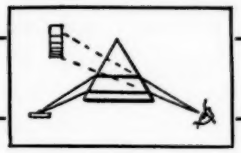
Journal of the OPTICAL SOCIETY *of* AMERICA

VOLUME 23
No. 3



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Published monthly by the

AMERICAN INSTITUTE OF PHYSICS

Incorporated

Prince and Lemon Sts., Lancaster, Pa.

Main Office: 11 East 38th Street, New York, N. Y.

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VOLUME 23 MARCH, 1933 NUMBER 3

Standing Light Waves; Repetition of an Experiment by Wiener, Using a Photoelectric Probe Surface

HERBERT E. IVES AND THORNTON C. FRY, *Bell Telephone Laboratories, New York, N. Y.*

(Received January 20, 1933)

A CLASSICAL experiment in optics was performed by Wiener[1] in 1890. By placing a thin photographic sensitive film at a small angle with a metal mirror, he demonstrated the existence of standing waves by getting traces of the loops of the waves in the developed film. Later a similar experiment was performed by Drude and Nernst, substituting a thin fluorescent surface as the probe. In these experiments the action of the light was found to be associated with the electric vector.

In recent studies which we have been making, in order to evaluate the influence of purely optical conditions on the photoelectric effect in thin films of alkali metals, we have been led to the view that the photoelectric emission from such films is directly correlated with the amount of energy absorbed by the films. According to this view, for which considerable support has already been given,[2] the peculiarities shown under polarized light are natural consequences of the fact, shown by detailed analysis of the optical factors, that the energy absorbed by the thin films deviates materially in amount from that which would be the case were the bulk absorption of the irradiated surface the significant factor, as had been previously generally assumed. The absorption in the film we arrive at by computation from the optical constants of the metal underlying the film, and of the film itself. The methods of computation prove to be the equivalent of determining the interference pattern above the metallic base, alone, and then regarding the alkali metal film as being immersed in this pattern. Looked at in this way the thin film of alkali metal plays the same rôle as the probe surface used by Wiener, Drude and Nernst, except that it is in contact with the reflecting surface instead of being at an angle to it. The present study was undertaken as part of the experimental support which was sought for our theory of photoelectric action, and had for its object lifting the sensitive film up to different positions above the reflecting metal surface, to find out whether the photoelectric current followed the very considerable alterations in the energy density which computations indicate. The experiment thus inspired is obviously a variant on the experiment of Wiener, and warrants the use of the title chosen.

[1] See Wood's *Optics*, 2nd Ed., p. 175 for a general account of these and other stationary light wave experiments.

[2] Ives, *The Vectorial Photoelectric Effect in Thin Films of Alkali Metals*, Phys. Rev. **38**, 1209 (1931); Ives and Briggs, *The Photoelectric Effect from Thin Films of Alkali Metal on Silver*, Phys. Rev. **38**, 1477 (1931); Ives and Briggs, *The Depth of Origin of Photoelectrons*, Phys. Rev. **40**, 802 (1932).

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By referring to Fig. 1, the nature of the experiment will be clearly seen. At the bottom of the figure is represented the underlying metal, for instance platinum, upon which to the left is shown a thin film of alkali metal, which is assumed, in accordance with several lines of evidence, to be only an atom or two in thickness. To the left is shown the relative energy density, as a function of distance above the surface, in two beams of light, incident at an angle of 60°

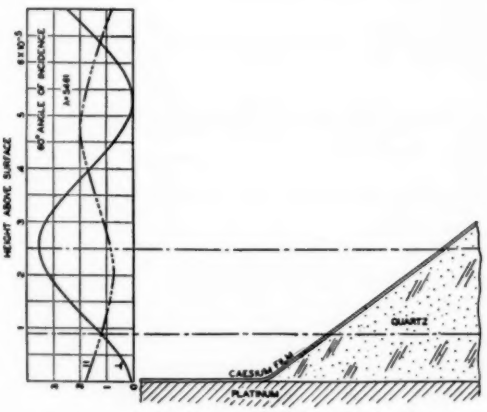

FIG. 1. Diagrammatic representation of experiment.

and polarized with the electric vector parallel (‖) and perpendicular (⊥) to the plane of incidence. It will be observed that in the layer occupied by the alkali metal film the intensity of the ‖ case is very much greater than the ⊥ case, in agreement with the experimental finding that the photoelectric current is much greater when the electric vector is parallel to the plane of incidence. It will be further observed that at various distances above the surface the relative values for the ‖ and ⊥ conditions assume a series of widely variant values.

Considering now the right-hand side Fig. 1, we have indicated the alkali metal film as being separated from and tilted with respect to the platinum surface. It is obvious that if the film could be held suspended in space in the position indicated it would cut through the standing wave pattern at different points along its length and we should expect the variations of photoelectric current to be similar to the variations in the standing wave pattern indicated at the left. Thus for the height indicated by the lower dashed line the two currents due to ‖ and ⊥ light would be equal, while at the height indicated by the upper dashed line the ⊥ current would be much larger than the ‖, in striking contrast to the conditions usually found with photoelectrically active surfaces.

Practically, it is not possible to thus suspend the alkali metal film, so that it becomes necessary to interpose some supporting material. We have chosen for this a wedge of quartz which is put down by evaporating or subliming from a tungsten filament sheathed in quartz beads. By properly choosing the distance and location of the filament with respect to the platinum plate it is possible to obtain a layer of quartz relatively thick near the filament and thinner as the distance increases. Thus we obtain a wedgelike support for our film, which, though its variation in thickness is not entirely uniform, is still quite good enough for a qualitative study.

Of course the interposition of the refracting layer affects the energy pattern, but this being susceptible of computation, the essential features of the experiment are not impaired. The experiment then consists in the preparation of such a quartz wedge in an evacuated tube, and the introduction of a small quantity of an alkali metal such as caesium, which is allowed to vaporize spontaneously until a photoelectrically active conducting film is obtained. This is then investigated for photoelectric sensitiveness at various positions along the length of the wedge, for various angles of incidence and conditions of polarization, and at different wave-lengths. For comparison with these experimental measurements, computations are made of the electric energy density along a perfect wedge, using the optical constants of the materials involved. The agreement between the experimental and computed values constitutes the test of the assumptions made with regard to the rôle of the optical conditions in the photoelectric effect from thin films.

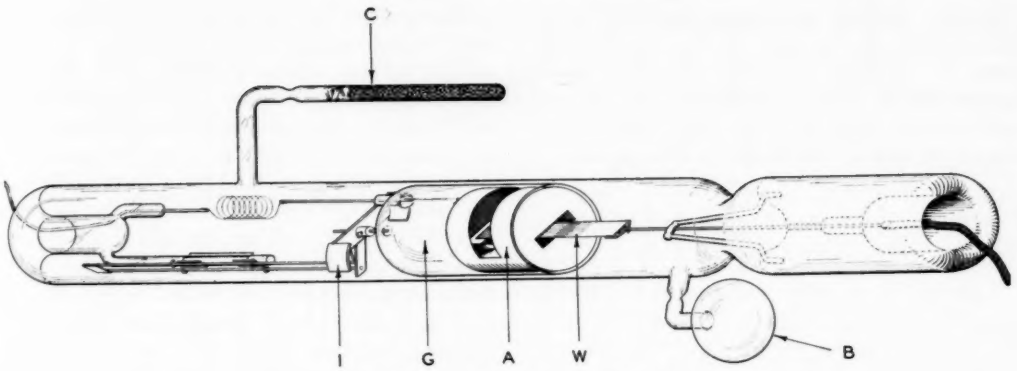

FIG. 2. Type of photoelectric cell used.

EXPERIMENTAL APPARATUS

A sketch of the type of photoelectric cell used in the experiments is given in Fig. 2. The quartz wedge on platinum (*W*) prepared in the manner described above, is mounted on a sliding carriage attached to the iron member *I*, so that it may be moved by means of an external magnet along the tube to expose it to the caesium vapor and also to place it conveniently within the collector. The tube is cylindrical in form and is mounted so that it may be moved parallel to its longitudinal axis and rotated so that the exciting light may strike the plate at any desired angle. The cradle for rotating it is provided with a divided circle so that angles may be chosen and read conveniently. The caesium is introduced by distillation into a side tube *B* from which a small quantity may be driven into the main tube, to serve as a supply for the spontaneous evaporation at room temperature, which is sufficient to deposit a photosensitive film. One of the chief experimental difficulties in this type of experiment is the diffusion of the caesium over all the walls of the tube, thereby introducing leakage currents. To minimize these, the cell was made very long and the anode was mounted in a glass sleeve *G*, closed at the end toward the leading-in wires. In addition, the amount of caesium introduced was purposely kept excessively small, the experiments being made with films which were very far from fully developed, but were nevertheless sufficiently sensitive for accurate measurement.

The appearance and properties of the quartz wedge deposited on the platinum plate warrant a brief description. Viewed by reflected light the wedge exhibits a series of faintly colored interference bands, some four or five millimeters apart. On long standing in the presence of alkali metal vapor these bands become intensified in color, because of the reflection of light back to the absorbing platinum surface. Ultimately the wedge becomes almost black, especially in the thicker portions. Part of the absorption of light is probably due to a slight granularity of the quartz deposit ("frilling"),[3] and this same roughness undoubtedly acts to depolarize the light and so impair the clear isolation of the photoelectric effects resulting from light polarized in the chosen planes. In the present experiments the measurements were all made with caesium films so thin as to have little effect on the intensity of the interference phenomena. For greater thicknesses the effect of the caesium film would have to be allowed for in the calculations which it was desired to check, thus introducing undesirable complications.

For illuminating the cell, a tungsten filament lamp with a quartz window was used in conjunction with a quartz monochromator and a quartz Rochon double image prism for polarizing the light. A variable angle prism made of two fused quartz wedges was introduced in the path of the double beam from the quartz Rochon prism, and shift from one plane of polarization to the other was made by rotation of the variable angle prism. The light spot used was about 1 mm in

[3] See Wood's Optics, 3rd Ed., p. 173.

diameter, and the optical adjustment was such that shifting of the spot on turning from one plane of polarization to the other was usually imperceptible. The photoelectric currents were read on a Compton electrometer with a high-resistance leak by the steady deflection method.

Calculation of the Electric Intensity in the Alkali Metal Film

The general methods by means of which the computations were made are entirely similar to those set forth in an earlier paper.[4] It was there shown that the electric force within a thin[5] film deposited on a massive base can be most easily found by first making some preliminary computations which have to do with reflection from the clean base. The exact process may be summed up in words as follows:

(a) We first ignore the presence of the film and find the phase and amplitude of the reflected beam just above the reflecting surface.

(b) We then add this vectorially to the electric force in the incident beam, thus getting the resultant force $\mathfrak{E}$ which would exist just above the surface if the film were not there.

(c) We then take account of the presence of the film by multiplying the normal component $\mathfrak{E}_z$ by a certain numerical factor g/g_1, which depends on the optical constants of the film, and which is the direct analogue for vibratory waves of the factor by which potential gradients change on crossing the boundary between materials of different dielectric constants.[6]

In this way we obtain the normal components of the electric force $\mathfrak{E}_1$ inside the film. The tangential components are the same as those of $\mathfrak{E}$.

Now the lamellar absorbing power of the film is known[7] to be proportional to $|\mathfrak{E}_1|^2$ which, in view of what we have said above, is $|\mathfrak{E}_x|^2+|\mathfrak{E}_y|^2+|g/g_1|^2|\mathfrak{E}_z|^2$. We can therefore find the amount of energy absorbed by the film directly from the components of electric intensity $|\mathfrak{E}_x|^2$, $|\mathfrak{E}_y|^2$, $|\mathfrak{E}_z|^2$ and the multiplying factor $|g/g_1|^2$.

Our present problem differs from the one previously discussed only in the nature of the base on which the film is deposited: where it was homogeneous before, it is now composed of massive platinum overlaid by a layer of quartz. As this difference does not affect the physical ideas outlined above, we can still compute our absorbing power from the same formula as before, provided we understand by $\mathfrak{E}_x$, $\mathfrak{E}_y$ and $\mathfrak{E}_z$ the components of electric force just above the stratified quartz-platinum surface. If, however, we assume the thickness of the quartz to be uniform throughout the region covered by our spot of light (although variable as the spot moves along the wedge), the amplitude and phase of the reflected light, and hence of $\mathfrak{E}$ also, can easily be found from the results of another paper.[8]

Thus we have at our disposal all the necessary machinery for carrying out the computational part of our program. Even so the matter of reducing the results to graphical form would still present rather serious practical difficulties except for the fortunate fact that the thickness of the quartz, t, and the wave-length of the light, λ, always appear in our reflection formulae in the combination t/λ, which may therefore be looked upon as a single variable. We can thus construct the master diagram of Fig. 3, which contains a family of curves corresponding to various angles of incidence, all of which have for abscissae the quantity t/λ.

In order to explain the ordinates on this master diagram it is necessary to go back and pick up a lost thread in our argument. We have said that the lamellar absorbing power of our film is proportional to $|\mathfrak{E}_x|^2+|\mathfrak{E}_y|^2+|g/g_1|^2|\mathfrak{E}_z|^2$, but we have so far said nothing about the factor of proportionality. From the exact relationship, which was given in Eq. (89) of *Plane Waves of Light III*, we find that this factor consists of $1/(\lambda \cos I)$, together with some incidental quantities which do not vary with λ, t or I, and are, therefore, of no interest in connection with our present study. Lumping these incidental factors

[4] Fry, *Plane Waves of Light III, Absorption by Metals*, J. O. S. A. **22**, 307–332 (1932).

[5] The limits of thickness for which the approximation is valid are explained in reference 4, p. 322.

[6] In the case of a film of unit permeability with air or vacuum above it, g/g_1 reduces simply to $1/(N+iK_0)^2$, N and K_0 being the optical constants of the film.

[7] Reference 4, p. 324.

[8] Fry, *Plane Waves of Light II, Reflection and Refraction*, J. O. S. A. **16**, 1–25 (1928). See in particular §17.

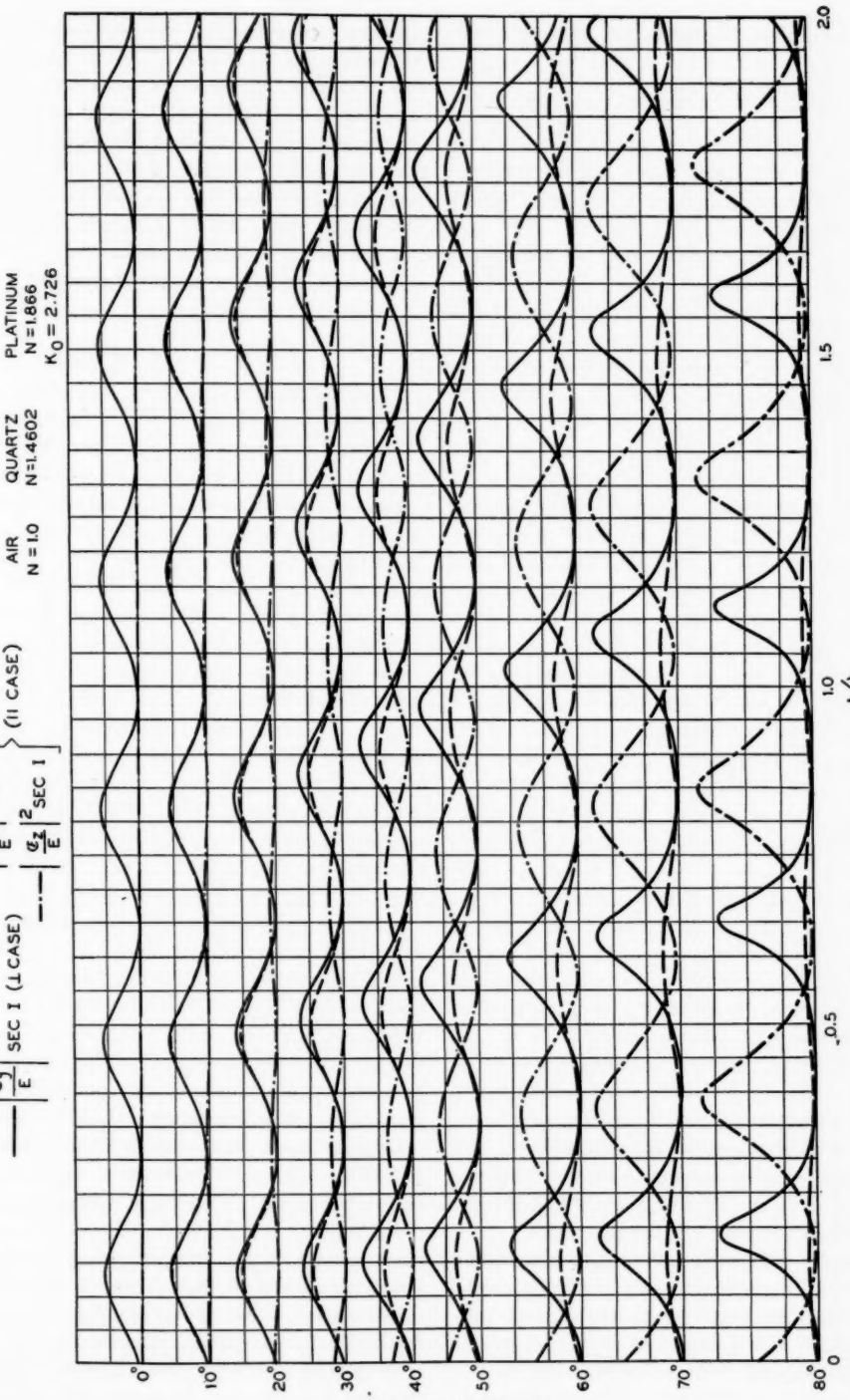

FIG. 3. Computed values of energy density at surface of quartz wedge on platinum, plotted against thickness/wave-length.

into the symbol B, we therefore have the equation

$$\lambda A_L = B(|\mathfrak{E}_x|^2 + |\mathfrak{E}_y|^2 + |g/g_1|^2|\mathfrak{E}_z|^2) \sec I.$$

We are now in position to explain the ordinates of our master diagram. They are exactly the quantities $|\mathfrak{E}_x|^2 \sec I$, $|\mathfrak{E}_y|^2 \sec I$, $|\mathfrak{E}_z|^2 \sec I$, which occur in this expression for λA_L.

The use of the diagram is simple. If our light is polarized with the electric vector normal to the plane of incidence, $\mathfrak{E}_x$ and $\mathfrak{E}_z$ are zero, and, except for a scale factor, the absorbing power of the film is obtained immediately by dividing the ordinate to the y-curve by the wave-length λ. If the light is polarized with its electric vector parallel to the plane of incidence we first read off the ordinate to the z-curve, multiply it by the "discontinuity factor" $|g/g_1|^2$, and then add the ordinate to the x-curve. When divided by λ the result is (except for the same scale factor B as before) the absorbing power for this plane of incidence.

For any given wave-length and angle of incidence the variation of absorbing power as our spot of light moves along the wedge can be obtained by reading from left to right along the curve which corresponds to the proper angle of incidence. It is not even necessary to divide by λ, which is constant along the curve, and can therefore be regarded as merged with the scale factor B.

Similarly, if the position of the spot of light on the wedge remains fixed and the angle of incidence is varied, we need only pick off points along a vertical line running through the whole family of curves. Again the divisor λ can be regarded as merged with the scale factor B.

If, on the other hand, we are interested in the variation of absorbing power with wave-length, all other factors remaining constant, we must choose the curve which corresponds to the proper angle of incidence and regard the abscissae as a scale of reciprocal wave-lengths. In this case the divisor λ becomes important.

Illustrations of the curves obtained in these various ways are given below in connection with the comparison between experimental and computed values.

Before leaving the master diagram Fig. 3, it is proper to point out that it is, in a strict sense, incomplete in that only a single pair of optical constants ($N = 1.866$, $K_0 = 2.726$) have been used for platinum and that one value ($N = 1.4602$) for the refractive index of quartz has been used throughout. Since both of these optical variables are reasonably constant through the visible region of the spectrum no serious error is introduced for our present purposes. Obviously for an absolutely complete treatment the variations of optical constants with wave-length should be introduced.

Experimental Results

The experimental results from which we give examples were obtained on two different tubes. The first of these, due to a loose contact in the platinum plate carriage could only be operated with the light incident at a considerable angle, so that with it measurements were made only at an angle of 60°. This tube served to give experimental data for the variation of photoelectric current along the wedge, and with wave-length, at the angle used. A second tube, which was free from this defect, was used for obtaining curves showing the variation of photoelectric effect with angle of illumination. Because of the use of different tubes, no direct correlations can be expected between the two sets of data; but this will be seen to be of little importance since all the significant behaviors predicted are found in one or the other of the two tubes.

Taking up first the variation of photoelectric current with thickness of the wedge, typical experimental results are shown in Fig. 4, where the abscissae give positions in millimeters of the spot of light relative to an origin near the thinnest point of the wedge, the latter point not being accurately determinable. In addition, because of the method of production of the wedge, it cannot be assumed that it is accurately triangular in vertical cross section. The abscissae therefore are to be considered merely as successive arbitrary points. Examination of the curves given in Fig. 4 shows at once a general agreement with the predictions of the theory as set forth in the master diagram. The emission curves pass through successive maxima and minima, the emissions for the two planes of polarization of the incident light reversing their position periodically. It is possible to pick out

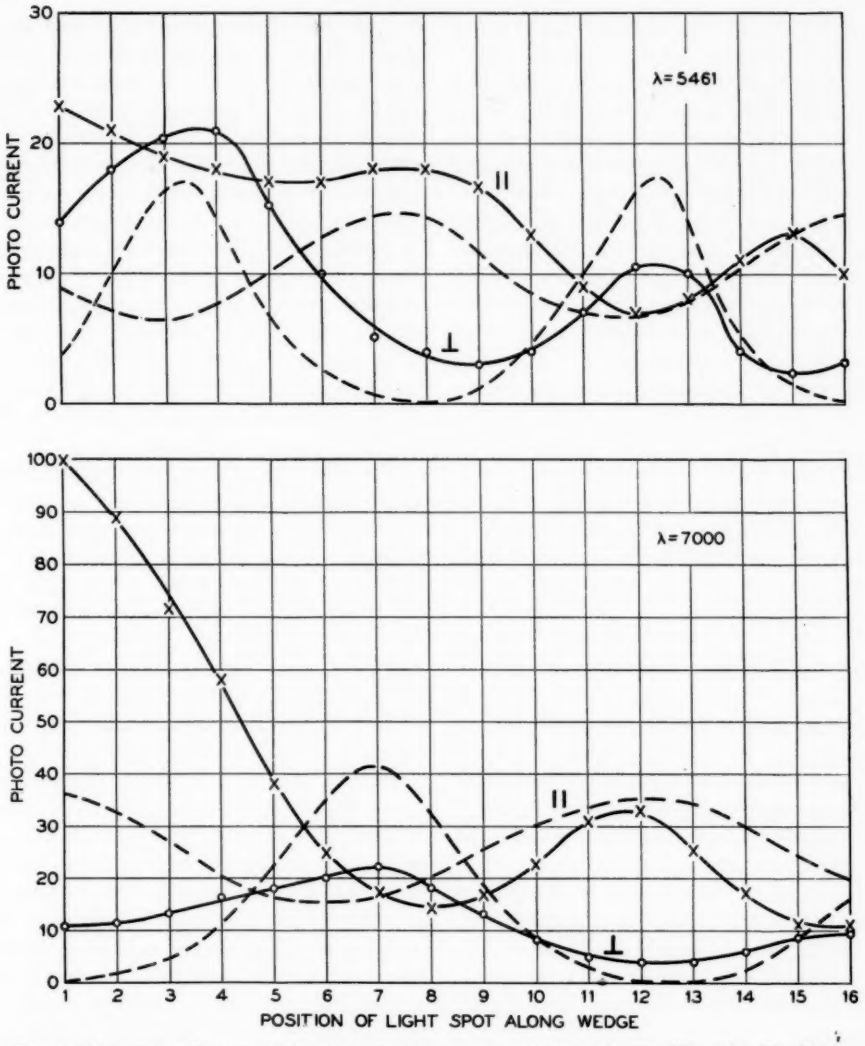

FIG. 4. Observed and computed values of photo-currents along wedge for 60° angle of incidence.

with some accuracy the actual thickness range covered by these measurements. By trial, it was found that the range from the positions 1 to 12, corresponds, in the case of wave-length 5461, to the extremes $t/\lambda = 0.51$ and $t/\lambda = 1.22$ on the 60° section of the master diagram, as is shown by the dashed curves in the figure, which were obtained by assuming $|g/g_1|^2 = 1$. For wave-length 7000, the corresponding range should be in the inverse ratio of wave-lengths, that is, $t/\lambda = 0.4$ and 0.95. By using these values in the master diagram the dashed curves in the lower figure are obtained, and it is seen that the maxima and minima have shifted quite closely in the manner to be expected.

It should be pointed out that for several reasons a positional and qualitative agreement is all that can be expected. For one thing, the spot of light used is relatively large with respect to the interference bands which are visible on examining the wedge. For another thing, the quartz wedge undoubtedly scatters considerable

light, thus deviating from the condition of transparency and specular surface which theory demands, whereby among other things the photo-currents suffer progressive diminution in value as the wedge increases in thickness. The fact that the wedge is probably not accurately flat on its top surface has already been mentioned. These more or less inevitable deviations from ideal conditions result in considerable flattening out of the maxima and minima and some shifting of their positions. The agreement between theory and experiment is, considering these limitations, very satisfactory.

Turning now to the distribution of photoelectric current with wave-length at different positions along the wedge, we show first in Fig. 5 (upper left-hand panel) the photoelectric emission with wave-length for clean platinum, from a section of the cathode which was shielded from the quartz carrying filament. This shows the rise of emission towards shorter wave-lengths and the somewhat greater emission for $\parallel$ light which is characteristic of the very thin film of caesium on platinum. No maxima or minima of emission occur in the wave-length region studied. In succeeding panels of the figure are shown wave-length distribution curves for positions 4, 7, 10 and 13 along the wedge. These are of quite different and extremely varied character, exhibiting not only pronounced maxima and minima of emission through the visible spectrum but periodic reversals of the strength of the photoelectric current for the two planes of polarization. Maxima in fact are present showing much the character of those produced by the action of a sensitizing glow discharge or other well-known procedures.

It is possible, by proper use of the master diagram, to check the experimental results with the theoretical ones. In order to make a complete check we would have to know the intrinsic photoelectric emissivity of the alkali metal, as a function of wave-length, and the multiplying factor by which the z component must be modified to take account of the optical constants of the film. These factors are not at present definitely known for caesium; the multiplying factor of the z component in fact probably depends upon the state of aggregation of the film, and we cannot even be sure that it is the same when it is deposited upon clean platinum and on the quartz base. In default of this information we have made the short cut of simply multiplying the experimental emission curves for the caesium film on clean platinum (upper left-hand panel of the figure) by the ratios of emission indicated by the master diagram, for various values of t/λ, arbitrarily selecting scale factors for the $\parallel$ and $\perp$ curves. The results are well illustrated by the lower right-hand panel, where curves so computed for $t/\lambda = 0.5$ are shown. These agree quite closely with the experimental curves for position 10 of this series[9] (upper right-hand panel) on the wedge, and show that the major characteristics of the experimental results are in satisfactory agreement with the theory.

The third set of data to be considered are the angle curves. The typical form of these curves for a thin alkali metal film on a base such as platinum is shown by the upper left-hand panel of Fig. 6. The emission due to light polarized with the electric vector in the plane of incidence rises to a sharp maximum at about 80° and falls rapidly to 90°, while for light polarized in the other plane, the emission falls off steadily from 0° to 90°. In the succeeding panels of Fig. 6 are shown a family of angle curves obtained for a series of positions along the wedge in the second tube. These exhibit a most extraordinary range of characteristics.[10] The emissions for the two planes of polarization alternate in position, and in place of the single maximum of emission characteristic of the platinum base we have multiple maxima exhibited. Again, as in the previous case, it is possible to build up from our master diagram angle curves which exhibit the dominant characteristics found experimentally. Illustrations of these are given in Fig. 7, computed by assuming, for convenience, the value unity for the multiplying factor $|g/g_1|^2$. These computed curves show in general the same type of behavior as the experimental ones. Because of the roughness of

[9] The curve shapes repeat the same general characteristics for a series of thicknesses, so that a greater value of t/λ would agree with the experimental data about as well, corresponding to the thickness estimate made from Fig. 4.

[10] The non-coincidence of the curves for 0° in certain cases is probably due to a slight shift of the light spot in turning from one plane of polarization to the other, in conjunction with irregularities in the wedge structure.

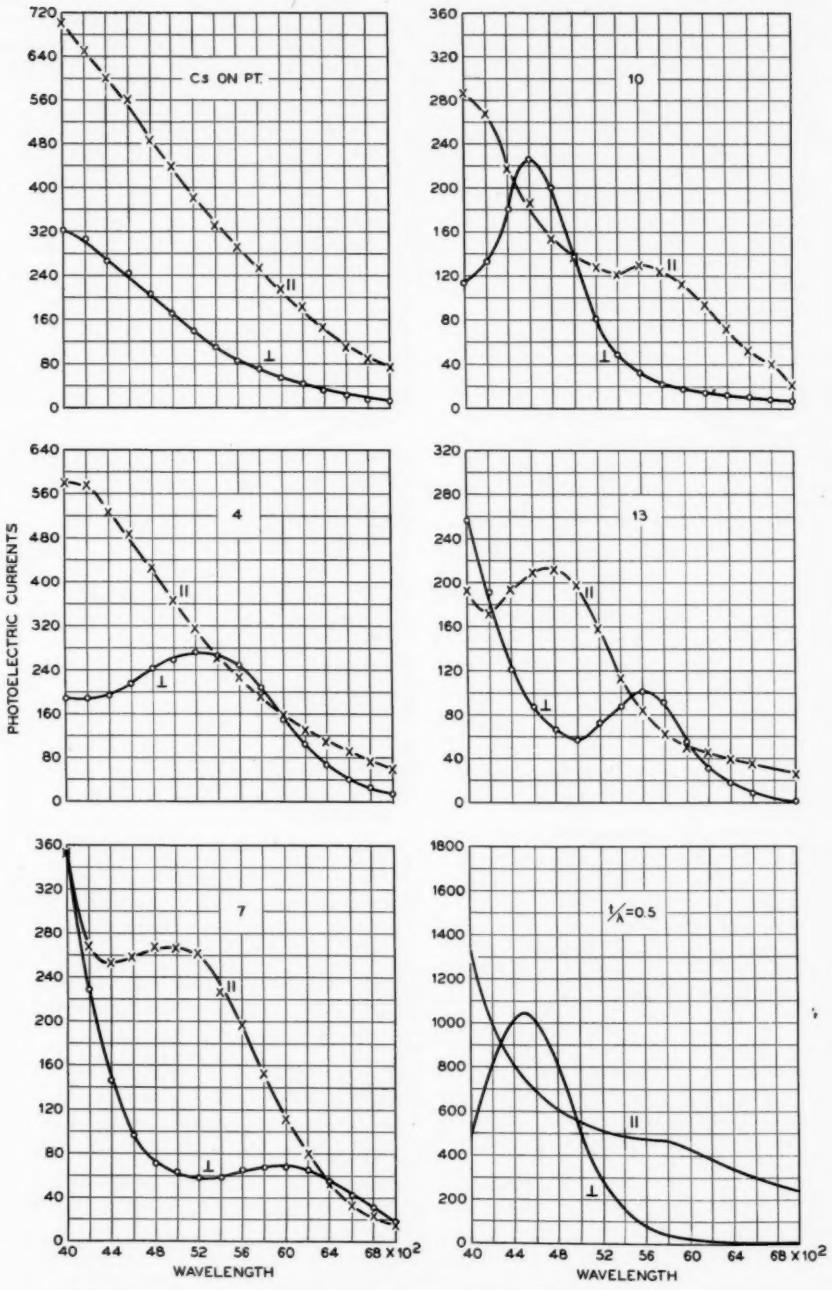

FIG. 5. Wave-length distribution of photo-currents for various positions on wedge.

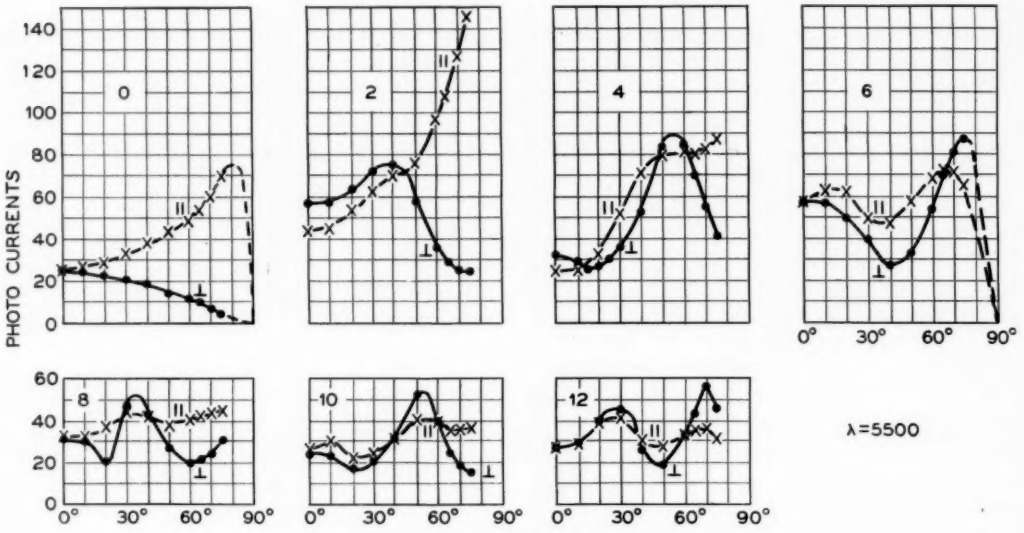

FIG. 6. Angle curves at various positions along wedge.

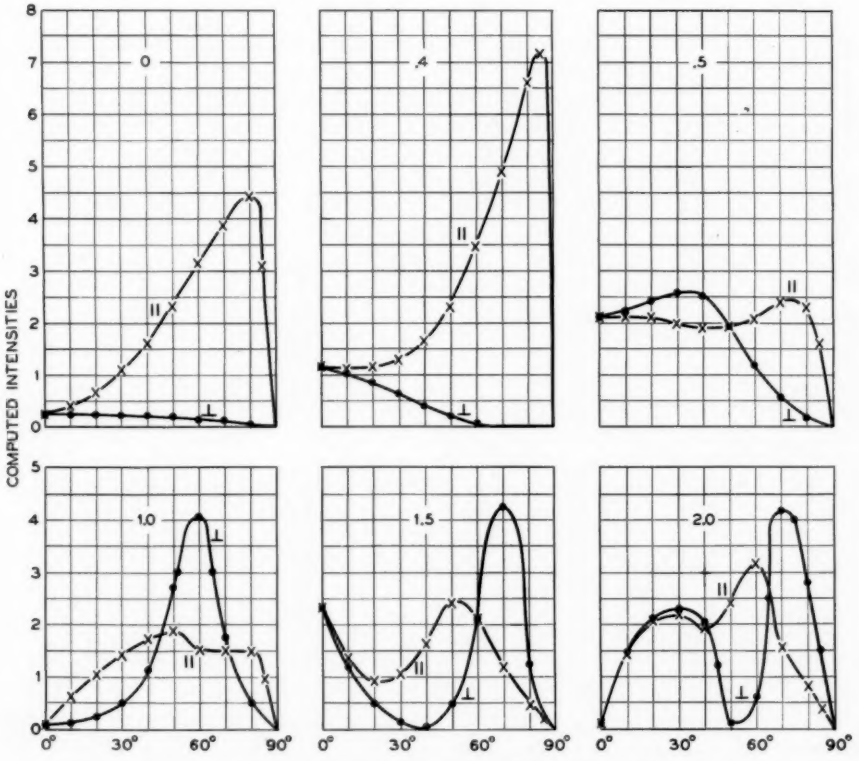

FIG. 7. Computed angle curves for various values of t/λ.

the quartz, already mentioned, the photocurrents are relatively too large at the small angles, but with this allowed for the check is quite satisfactory. It appears from this test, that the quartz wedge in this second tube, over the region which it was possible to measure, is everywhere of considerable thickness, the angle curves characteristic of thicknesses less than $t/\lambda = 0.4$ not being found. We have, however, found these in other experiments which will be reported on in another connection.

Discussion

The results of this study, considered from an optical standpoint, constitute a further and more detailed confirmation of the point in classical wave theory investigated by Wiener. By the use of the photoelectric probe surface quantitative measurements have been possible in place of the purely qualitative observations which the photographic and fluorescent methods yield. While the measurements here recorded are in certain respects rather crude, it appears likely that if the scale of the apparatus were enlarged, if methods of preparing considerably longer wedges of clear transparent material were developed, and if the intrinsic photo-emissivity and optical constants of the alkali metal film were accurately known and used, a very complete quantitative check on the theoretical computations would be obtained. There is probably no doubt at the present time that the classical wave theory covers the case, and pushing the experiments beyond the present point is hardly warranted.

From the standpoint of photoelectric theory, for which the study was undertaken, the results give added support to the line on which we are studying the photoelectric effect from thin films of alkali metal. The experiment has in fact carried the investigation of the relation between electric intensity and photoelectric current up away from the metallic base, to which experiments were previously confined, into the space above. Here, according to the theory, quite unusual photoelectric phenomena were to be expected, and have now been observed.

The experiment also has an important bearing on the whole question of spectral maxima and minima of emission in photoelectric cells in which the alkali metal surface has been given any sort of sensitizing treatment. The similarity of the maxima of emission here brought about by lifting the sensitive layer away from the underlying metal, to the maxima produced by subjecting the surface to a hydrogen glow discharge and other processes is so striking as to suggest the futility of theoretical speculation correlating these maxima with atomic, crystalline, or wave mechanical factors until the purely optical factors have been evaluated.[11] A case in point is the very efficient type of cell in which a sensitive surface containing caesium is developed on an oxidized silver plate. It has recently been found possible in these laboratories to produce cells of this type with plates of specular silver. These cells exhibit interference colors, which indicate that the silver oxide acts as a transparent supporting layer, similar to the quartz wedge here used. The spectral maxima and minima of emission exhibited by these cells are undoubtedly influenced by the optical conditions described in this paper, and these latter must be allowed for before intrinsic emissive properties can really be established, much less explained. The subject matter of this paper may be considered to some extent as preparatory work to the further study of the caesium-silver-oxide cell.

We are greatly indebted to Mr. G. R. Stilwell for the measurements reported in this paper, and to Miss C. L. Froelich for the extensive computations necessary.

[11] The interesting experiments of Suhrmann (Phys. Zeits. **32**, 216 (1931)) where exposure to vapors of naphthalene and paraffin modified the selective photoelectric effect of a potassium surface, are possibly subject to reinterpretation on an optical rather than the chemical basis favored by Suhrmann.

A Multiple Prism Glass Spectrograph

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(Received September 27, 1932)

A spectrograph has been designed and constructed by the author which has the following characteristics: (1) It can be used to solve nearly every problem which requires the use of a glass prism spectrograph and a number of problems for which a 21-foot grating is usually required. (2) In the violet it is equivalent to a 21-foot 15,000 lines to the inch grating in the second order with respect to resolving power and dispersion, and is free from ghosts. (3) The mounting is arranged in such a manner that more than 20 combinations are available by rather simple adjustments, giving a wide range of photographic speeds and dispersion. (Table I shows dispersion obtainable with different combinations of prisms and lenses.) (4) The spectrograph was constructed in our shop at a cost for optics and materials no greater than the cost of a small ready made single prism spectrograph.

THE purpose of constructing this instrument was twofold: (1) To obtain resolving power and dispersion comparable to a 21-foot grating with the distinct advantage over a grating of freedom from ghosts. (2) To design the mounting in such a manner that a large number of combinations of prisms and lenses are available by means of rather simple adjustments, giving a wide range of photographic speeds and dispersion.

OPTICS

The optics, slit, and plate holder were purchased from the Bausch and Lomb Optical Company. The 60° prisms, six in number, are made of glass of $N_d = 1.62$ and have a base length of 85 mm and are 50 mm high. They are very homogeneous and satisfactory in every respect. The slit is the same as supplied with the Bausch and Lomb large quartz Littrow spectrograph. The collimating lens is a telescope objective of 60 mm aperture and 90 cm focal length.

The following camera lenses are available: First, a lens the same as the collimating lens (speed effectively F 18); second, a lens of 35 cm focal length speed F 7; third, a Zeiss Tessar (Bausch and Lomb) speed F 4.5; and fourth, a lens of more than two meters focal length, speed greater than F 40 will be supplied.

CONSTRUCTION

The prism table is of cast iron and is 18 inches in diameter. It is mounted, as can be seen, in Fig. 2, on 6-inch channel iron which is in turn mounted on pipe fittings. The pipe fittings are mounted on flat steel plates and are provided with leveling screws so that the leveling of the instrument may be easily accomplished. The bench carrying the camera arm is of similar construction, and the entire mounting is braced with angle iron. This construction has shown itself to be very sturdy, and no trouble has been experienced from vibrations.

The camera unit is provided with a linear adjustment for focussing which is controlled by means of a screw, the setting of which can be read from an engraved scale and micrometer screw head. The plate holder carriage is constructed so that it can be made to rotate about an axis which passes through the emulsion in the center of the photographic plate. Thus it is only necessary to bring a line into focus in the center of the plate and then to rotate the holder until as large a portion of the spectrum as possible comes into focus. This angular adjustment is also provided with a scale and micrometer.

The collimating tube is a brass tube with a smaller brass tube about a foot long which makes a slide fit inside the larger tube. The slit screws on to the end of the smaller tube, and a micrometer adjustment is provided to set the collimator for parallel light. The collimating tube is firmly mounted in three split steel yokes which are accurately lined up and mounted on a heavy steel plate, and the whole unit firmly bolted to the channel iron base.

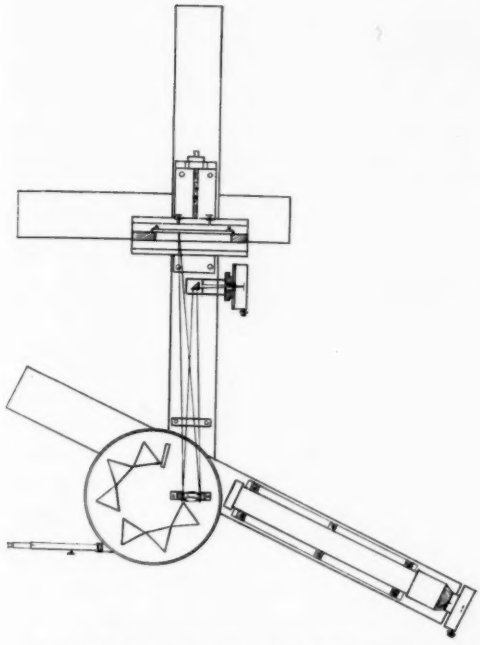

FIG. 1. Horizontal section of the Littrow mount.

The objective lens for the six-prism mount is carried on the camera arm, which can be rotated so that it brings camera and lens into correct position for the various wave-lengths for which the prisms can be set. The optical set-up shown in Fig. 2, which is one of the many combinations available, is similar to that described by J. S. Foster.[1] However, the mounting is quite different in that no castings are used except the prism table.

A small auxiliary telescope is provided which is carried on an iron ring, machined so that it can be made to travel smoothly around the prism table. This feature makes it very easy to set the prisms. This telescope has been found to be very useful during photographing; since it can be set to catch the light escaping from the first or second prism, thus enabling one to follow the character of the spectrum in the longer wave-lengths while photographing in the blue and violet.

Littrow mount

A large Littrow instrument has been described by P. Weiss and R. Fortrat[2] in which are used five 60° prisms and a half prism mounted on a Hamy train and collimated by means of a concave mirror.

Since the primary object of constructing this instrument was to secure versatility with respect to dispersion, dispersion interval, resolving power, and speed, no linkage is used for the prisms. The mountings are constructed so that different combinations of prisms and lenses can be used by making rather simple adjustments.

It can be seen by referring to Fig. 2, that the prisms do not set on the prism table but are raised above the table by being mounted on steel prisms to which they are cemented. The reason for this arrangement is twofold: First, to enable one to move the lens into position on the prism table, as shown in Fig. 1, when using the Littrow mount. Second, to enable one to set the short focus cameras (F 4.5 and F 7) on the prism table when using these fast combinations.

The optical set-up with six prisms in the Littrow mounting is shown in Fig. 1. The light is reflected back through the prism train by means of a "Penta" mirror (supplied by Bausch and Lomb).

In order to change from the conventional to the Littrow mount, it is only necessary to remove the camera box and bolt the attachment for holding the slit and right-angled prism into

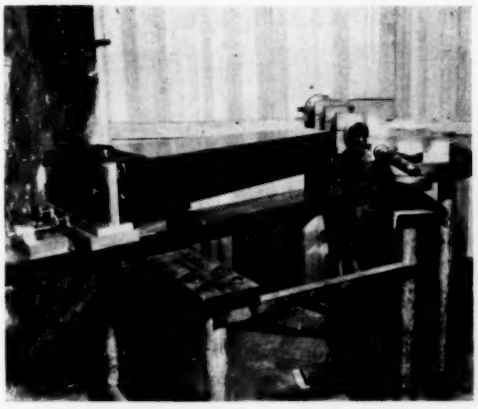

FIG. 2. Photograph of six prism instrument in conventional mount.

[1] J. S. Foster, J. Opt. Soc. Am. 8, 373 (1924).

[2] P. Weiss and R. Fortrat-Archives des Sciences 35, 5–27 (1913).

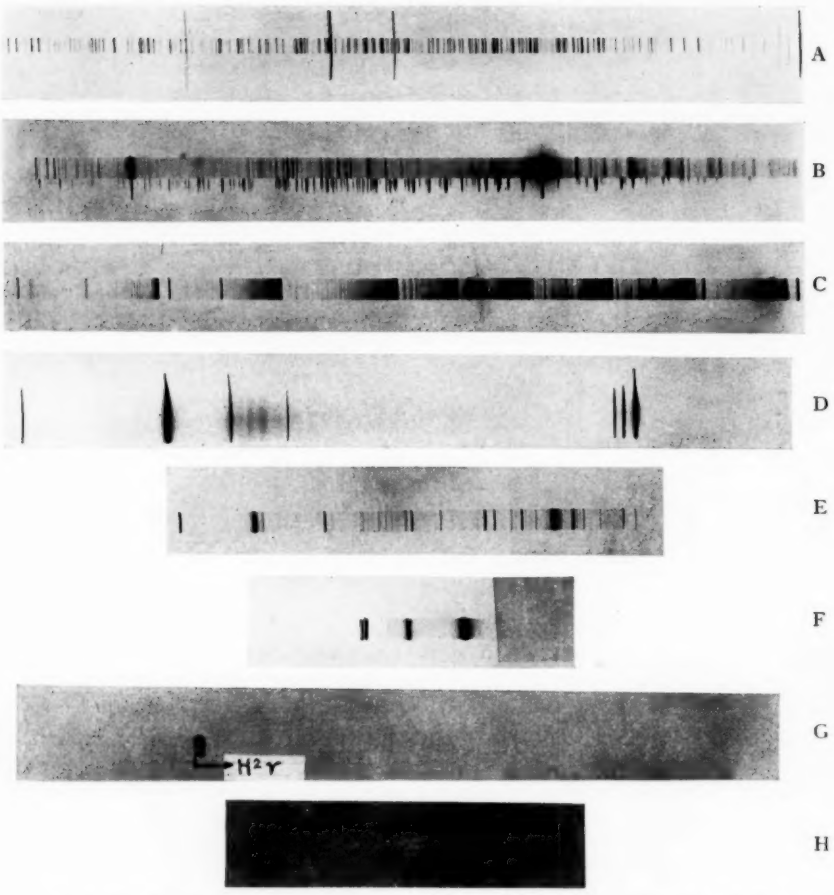

FIG. 3. Samples of work done to date with the multiple prism spectrograph with both conventional and Littrow mounts.

position as shown in Fig. 1. The slit is then removed from its position at the end of the collimator tube and put into proper position on the Littrow attachment. The objective lens is moved into position on the prism table, close to the face of the first prism to be set, and then adjusted for parallel light. The prisms are then set in the regular manner and the reflector adjusted so that the spectral region for which the prisms were set comes into proper position with respect to the photographic plate. In about an hour's time the change from conventional to Littrow mounting and focussing of the instrument can be accomplished.

It is possible to eliminate most of the diffusely reflected light from the lens by using the lens slightly off the axis. This is necessary when working with spectra of small relative intensity to prevent general fogging of the photographic plate.

Table I shows the dispersion obtained with different combinations of lenses and prisms that are available (4100 Angstroms).

The spectrograms shown in Fig. 3, are contact prints (not enlargements) and are mounted with the violet side on the left.

A, *B*, *C*, and *D* of Fig. 3, were taken with six prisms in the conventional mount with the F 18 objective lens. *A* is a mercury arc spectrum in the 4047 region with iron arc comparison spec-

TABLE I.

Conventional Mount			*Littrow Mount*		
No. of prisms	objective	dispersion A/mm	No. of prisms	objective	dispersion A/mm
6	F 45	1.3	1	F 45	3.6
6	F 18	3.2	2	"	1.8
6	F 7	8.2	3	"	1.2
3	"	16.4	4	"	0.90
2	"	25.0	5	"	0.72
1	"	50.0	6	"	0.60
1	F 4.5	80.0	1	F 18	6.6
2	"	40.0	2	"	3.3
3	"	26.6	3	"	2.2
4	"	20.0	4	"	1.7
6	"	13.3	5	"	1.3
			6	"	1.1

trum. *B* shows Hδ and Hγ along with the secondary spectrum of hydrogen, with iron arc comparison spectrum. *C* shows some bands which appeared in one of the author's hydrogen discharge tubes in the early stages of operation, (in the Hδ region). The original plates show several of these bands resolved clear to the heads of the bands. *D* is the Raman spectrum of ethyl ether in the 4047 region which was obtained with an exposure time of only five hours and shows clearly the broad diffuse character of these so-called Raman lines.

E, *F*, and *G* were taken with six prisms in the Littrow mount with the F 18 objective lens. *E* is the spectrum of the iron arc in the Hγ region and shows all the lines in this region listed by Kayser, and was obtained with an exposure time of only a few seconds. *F* shows the 4358 group of mercury and also Hγ. *G* shows the line due to the isotope of hydrogen of mass two ($H^2\gamma$) the existence of which was shown by Urey, Brickwedde, and Murphy[3] by using the second order of a 21-foot grating. The author[4] has been able to confirm the above, using this instrument, which definitely eliminates grating ghosts from the picture.

H was obtained with four prisms and the F 4.5 camera (dispersion 20 A/mm) and is the Raman spectrum of ethyl alcohol which was obtained with an exposure time of 3.5 and 7 minutes, respectively. An exposure time of $1\frac{3}{4}$ minutes was sufficient to make all these lines visible on the plate.

The author wishes to express his appreciation to Dr. W. R. Ham for the suggestions offered during the designing of the mounting of the instrument. Also to Mr. T. D. Decker, our mechanician, for his help with the machine work.

[3] Urey, Brickwedde and Murphy, Phys. Rev. **40**, 1 (1932).

[4] Rank, Phys. Rev. **42**, 446 (1932).

Some Infrared Interference Spectra

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(Received December 28, 1932)

WHILE recording the infrared transmission of thin sheets of cellophane and mica to see if there is any relation between absorption and double refraction in these materials, complicating interference effects entered. Series of some sixty or seventy interference maxima and minima were regularly superimposed upon the continuous spectrum, along with well-known absorption bands caused by water vapor in the atmosphere through which the light beam passed. The portion of the spectrum recorded lies between the visible and 2.75μ, and was produced by a new automatically recording quartz spectrograph to be described elsewhere. It seemed to the writer that these records were of sufficient interest as examples of channeled spectra in the infrared to merit their reproduction in an optical journal.

Meyer and Bronk,[1] while using thin mica end plates on absorption cells in studying absorption in the region of 3μ, found complicating interference effects present even though the beam was a converging cone of 10°. Schaefer, Bormuth and Matossi,[2] in examining the absorption of a 0.07 mm specimen of calcite overlooked the possibility of interference in a section of this thickness and, as shown by Taylor and Rideal,[3] interpreted several interference minima as true absorption bands.

In the present instance the thin specimen producing interference was placed in the converging beam directly before the slit of the spectrograph. The angle of this cone was about 20° whenever the full aperture of the collimating mirror in the spectrograph was utilized, but because of the chromatic and spherical aberrations of the condensing lenses the actual cone utilized, associated with any portion of the spectrum, was not known.

The first interference encountered was in a piece of cellophane, 0.023 mm thick. W.E. Hammond[4] has pointed out that cellophane is doubly refracting. A sample was cut from a roll of this material and it was found that the directions of vibration were along and across the roll, a fact to be expected regardless of whether the double refraction arises from molecular alignment or from stresses set up during the manufacture of the material. In Fig. 1B is a reproduction of the interference spectrum produced when the electric vector of the light beam vibrated in a direction corresponding to the length of the roll, whereas Fig. 1C represents vibration across the roll. Polarization was produced by inserting a pile of thirteen clear glass plates in the parallel beam between the two lenses which constitute the condenser system. To indicate what features of the record are not caused by interference, Fig. 1A is included, showing the energy distribution of the tungsten lamp modified by atmospheric water-vapor bands at 1.1μ, 1.4, 1.9 and 2.7, and by absorption at 2.20μ by the glass wall of the lamp source. The cellophane itself was apparently too thin to introduce any observable absorption bands of its own.

If interference were produced in parallel light by a piece of cellophane of uniform thickness, the variation in intensity between maxima and minima would be of the order of 18 percent. The variations in Figs. 1B and 1C are less than half this amount, are greater in 1C than in 1B, and become smaller in both records as shorter wavelengths are approached. There are at least three reasons for this smaller intensity variation. Stated in the decreasing order of their probable importance they are as follows: the convergence of the rays, nonuniformity in thickness or nonhomogeneity in the specimen, and the resolving power of the spectrograph. For the sample under

[1] Meyer and Bronk, Astrophys. J. **59**, 252–258 (1924).

[2] Schaefer, Bormuth and Matossi, Zeits. f. Physik **39**, 648–659 (1926).

[3] Taylor and Rideal, Phil. Mag. **4**, 682 (1927).

[4] Hammond, Science **76**, 125 (1932).

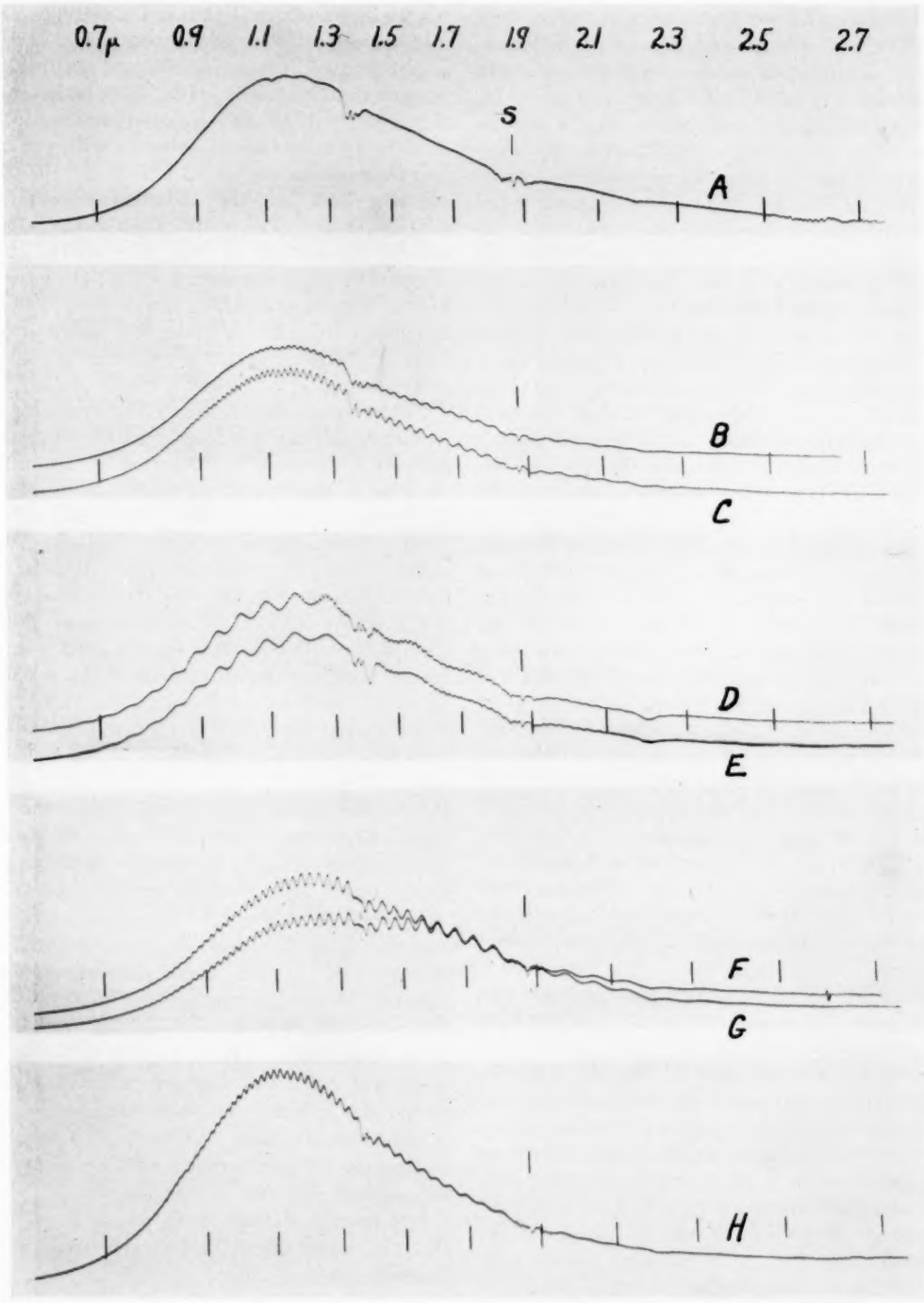

FIG. 1. Interference spectra. *B* and *C*, in 0.023 mm of celophane; *D* and *E*, in a piece of split mica 0.15 mm thick; *F* and *G*, in 0.016 mm of mica; *H*, in 0.031 mm of air.

consideration calculation shows that convergence of the rays should completely prevent the formation of maxima and minima when a wave-length of about 0.5μ is reached. The contribution by nonuniformity and nonhomogeneity would be difficult to determine, although these are probably the cause for the difference between records 1B and 1C. That the finite resolving power of the spectrograph cannot contribute appreciably to this lowered intensity variation between maxima and minima will be seen from the slit width indicated on each spectrum.

The first sample of mica studied was a section 0.15 mm thick which proved to be made up of two pieces separated by an air film of the order of 0.005 mm. Interference in this air film was responsible for the more widely spaced maxima and minima of Figs. 1D and 1E, whereas the smaller interference bands were produced in the two mica sheets themselves. The record of Fig. 1D was taken with the electric vector of the light vibrating in a plane perpendicular to the plane including the two optic axes of the mica and the normal to the surface, whereas in Fig. 1E the vibration was in this plane. Two absorption bands characteristic of mica appear at 2.21μ and 1.407μ. The former is relatively independent of the direction of the electric vibration, but the latter is associated predominantly with vibrations in the plane of the axes. The 1.407μ band is doubtless produced by vibrations of the hydrogen atoms in the crystal, and because of its sharpness and higher frequency compared with the corresponding band in ice and water, it indicates that the hydrogen atoms in muscovite mica do not occur as parts of molecules of "water of crystallization."

A sample of mica of 0.016 mm thickness was next used. The record of Fig. 1F was obtained with the electric vibrations in the plane of the optic axes, whereas that of Fig. 1G had the vibrations at right angles to this plane. Care was taken to leave the specimen unaltered in position in these two records, so that any differences introduced must be attributed to different values of the refractive index rather than to an altered thickness of crystal. Edser in his *Light for Students* (p. 554, 1930 edition) erroneously states that the two principal indices of refraction effective under the conditions of this experiment are the intermediate (1.580) and the least (1.551), and consequently it was expected that Fig. 1F would contain $1\frac{1}{2}$ more interference maxima and minima than that of Fig. 1G. There is, however, about $\frac{1}{4}$ of a fringe difference between these two records, an observation consistent with the true fact that the two principal indices of refraction effective here are the intermediate and the greatest (1.585). The modification in the general energy distribution in Fig. 1G, causing it to cross and recross the record of Fig. 1F, is to be explained upon a consideration of the rotational dispersion in, and the reflection losses at the faces of, the two crystalline quartz prisms of the spectrograph.

Upon the assumption that interference fringes formed in this manner could possibly be used to measure the indices of refraction of liquids, an air film of 0.031 mm thickness was produced between 4 mm fused quartz plates whose faces had not been polished for work of this type. The result obtained with completely unpolarized light is shown in Fig. 1H. Calculation shows that if the whole cone of 20° were effective in the spectrograph, interference maxima and minima should disappear for wave-lengths about 0.95μ. In reality they persist down to the visible, indicating that the effective cone was much less than 20°.

If the space between two parallel glass or quartz plates were filled with a liquid the interference destroying effects which occur for shorter wave-lengths would be lessened, as in the case of a thin crystal, because of the cutting down of the effective angle of the light cone upon refraction into the liquid. The ratio of intensities between maxima and minima would decrease greatly, however, because of the slight difference in the indices of refraction of the liquid and the plates. If the inside faces of the plates be half-silvered, as in a Fabry-Perot interferometer, not only should this difficulty be overcome but also the maxima should become very sharp. It is proposed to attempt the measurement of some refractive indices in the infrared in this manner.

Interference *maxima*, such as those in Figs. 1B–1H, occur when the following equation is satisfied,

$$2\mu t \cos r/\lambda = N, \qquad (1)$$

in which μ is the refractive index, t the thickness, N an integer, and r an *average* angle of refraction within the specimen. Assuming μ constant, we have

$$-(2\mu t \cos r/\lambda^2)\Delta\lambda = \Delta N. \qquad (2)$$

From (1) and (2) we get

$$N = -(\lambda/\Delta\lambda)\Delta N. \qquad (3)$$

Thus, without knowing the values of t and r, by merely measuring the wave-length interval $\Delta\lambda$ corresponding to a whole number of fringes ΔN, the assignment of numbers N to the various maxima can be made. Such an evaluation has been made from the records of Figs. 1C, 1G and 1H. Eq. (1) shows that if values of N be plotted against the reciprocals of wave-length, namely wave numbers, a curve passing through the origin should result. Moreover, if the refractive index μ be constant, as in air, Fig. 1H, the curve should be a straight line. The plotted data of Fig. 2B bear out this simple theory. μ could scarcely be considered constant for either cellophane or mica. Thus, when the lowest points for mica in Fig. 2C are connected with the origin by means of a straight line, this line extended deviates more and more from the actual plotted points. This deviation is a measure of the dispersion in mica. In the case of cellophane the plotted points accurately fit a straight line passing through the origin, indicating a very low dispersion in this material. In fact, advantage was taken of this fact to use interference maxima 83–100 to extend the calibration of the plate between wave-lengths 0.87μ and 0.71μ.

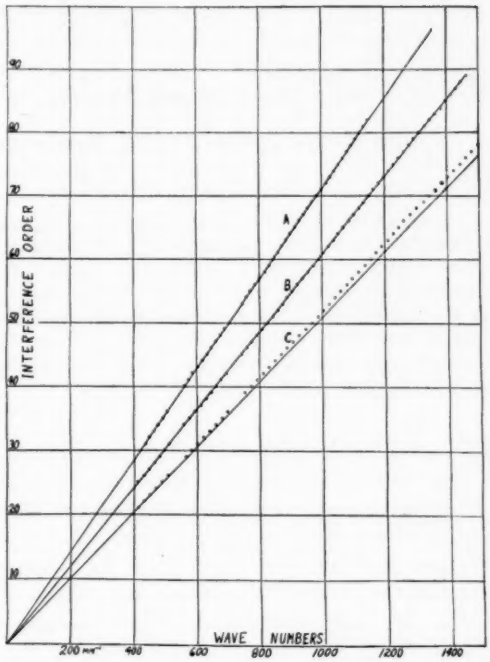

FIG. 2. Relation between wave number and interference order number. *A*, cellophane; *B*, air; *C*, mica.

The Infrared Absorption Spectra of Certain Alkaloids

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(Received July 23, 1932)

The absorption of twelve alkaloids was investigated between 1.00μ and 12.00μ with constant deviation spectrometers employing rocksalt and fluorite prisms. The compounds investigated were α-β-dipyridyl, anabasine, neo-nicotine, methyl anabasine, nicotine, spartine, spartine sulphate, pelletierine, arecoline, arecoline hydrobromide, pilocarpine, and pilocarpine hydrochloride. Anabasine and neo-nicotine are presumably the same alkaloid, anabasine being a plant extract and neo-nicotine a synthetic product. They show, however, different absorption characteristics. As is to be expected the absorption bands corresponding to the C−N, C−H, C−H_2 and benzene ring frequencies are present.

IN surveying the subject of infrared absorption, the fact was revealed that little attention has been given to the absorption of the alkaloids. The only investigations reported so far are those by Bell[1] and Spence[2] who investigated the absorption spectra of a few alkaloids between 1.00μ and 12.00μ. In this investigation the absorption spectra of twelve more alkaloids covering the same spectral range were obtained. The substances investigated were: (1) α-β-dipyridyl, (2) *l*-β-pyridyl-α'-piperidine or anabasine, (3) β-pyridyl-α'-piperidine or synthetic neo-nicotine, (4) *l*-β-pyridyl-*N*-methyl-α'-piperidine or methyl anabasine, (5) β-pyridyl-α-*N*-methyl-pyrrolidine or nicotine, (6) spartine, (7) spartine sulphate, (8) α-piperidyl-β-propionic aldehyde or pelletierine, (9) *N* methyl-Δ^{β}-tetrahydronicotinic acid methyl ester or arecoline, (10) *N* methyl-Δ^{β}-tetrahydronicotinic acid methyl ester hydrobromide or arecoline hydrobromide, (11) pilocarpine, (12) pilocarpine hydrobromide.

A constant deviation spectrometer of the Wadsworth type was employed for this work. A sketch of it showing at the same time the arrangement of the light source is given in Fig. 1. This sketch is self-explanatory. Constant deviation is obtained as usual by having the prism *P* and plane mirror M_3 mounted together on a table which is rotated by means of the micrometer screw *D*. A drum attached to this screw had a close spiral engraved on it which was carefully calibrated to read wave-lengths in steps of 0.01μ from 1.00μ to 12.00μ. The prism was of rocksalt with faces 35 mm by 45 mm.

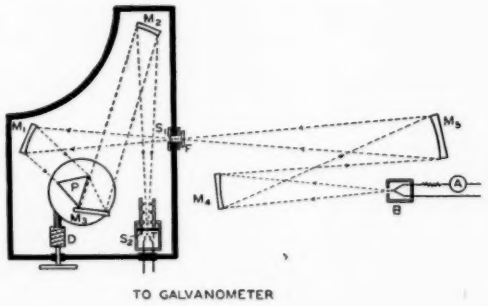

FIG. 1.

The absorption cell is placed at *F* and arranged on a shutter so that it can be replaced by a rocksalt plate of the same thickness. The thermopile at *T* was of the Coblentz type and showed fairly good sensitivity. As precaution against drift, the thermopile arm of the telescope was packed with cotton. The spectrometer was inclosed in a nearly airtight iron box with a drying system attached to preserve the prism. A Weston D'Arsonval galvanometer was used. Its current sensitivity was 1.5×10^{-9} amperes, with a critical damping of 12 ohms and a period of 10 seconds. The usual lamp and scale were used for measuring galvanometer deflections. The deflections were of the order of 150 mm. In order to suppress extraneous vibrations of the galvanometer, it was mounted on a slab of marble supported by six tennis balls and some layers of felt.

[1] Bell, J. Pharmacology **29**, 533 (1926).
[2] Spence, Astrophys. J. **39**, 243 (1914).

TABLE I. *Wave-lengths of absorption bands in microns (μ).*

Fig. 2	Fig. 3	Fig. 4	Fig. 5	Fig. 6	Fig. 7	Fig. 8	Fig. 9	Fig. 10	Fig. 11	Fig. 12
1.78	1.75	1.75	1.77	1.15	1.35	1.20	1.88	1.78	1.74	1.17
2.48	2.47	2.46	2.43	1.80	1.75	1.40	2.45	2.43	2.32	1.70
2.92	2.98	3.00	3.43	2.40	2.48	1.85	3.05	3.01	2.43	2.37
3.35	3.43?	3.40	3.70	2.98	2.98	2.45	3.47	3.40	3.43	3.15
3.85	3.60	4.30	4.20	3.43	3.43	2.98	4.60	3.68	3.89	4.04
4.25	4.25	4.50	4.45	3.60	3.55	3.43	4.78	4.23	4.70	4.35
4.58?	4.45	5.16	4.85	4.25	4.32	3.95	5.37	4.50	5.22	4.57
5.21	5.25	5.38	5.25	4.60	4.50	4.55	5.85	4.73	5.77	4.90
5.61	5.82	5.60	5.98	4.90	5.00	5.35	6.15	4.95	5.97	5.62
6.25	6.08	5.90	6.31	5.22	5.37	5.85	6.28	5.18	6.18	6.03
7.00?	6.32	6.24	6.60	6.00	5.85	6.18	6.82	5.32	6.98	6.30
	6.88	6.45	6.88	6.30	5.95	6.86	6.90	5.70	7.91	6.80
	7.08	6.85	7.35	6.80	6.10	7.44	7.10	6.01	8.95	7.10
	7.52	7.30	7.50	7.35	6.35	8.20	7.70	6.20	9.23	7.40
	7.75	7.55	7.75	7.55	6.86		8.20	6.73	10.21	8.20
	8.37	7.90	7.95	8.20	7.20		8.63	7.10	10.90	8.48
	8.90	8.35	8.40	8.40	7.45		9.10	7.65		9.10
	9.15	8.75	9.00	9.00	7.70		9.25	7.85		9.83
	9.60	9.00	9.35	9.45	8.35		9.63	8.45		10.10
	10.40	9.35	9.62	9.60	8.98		9.95	8.70		10.52
	10.60	9.50	10.18	9.75	10.00		10.45	8.90		11.10
	10.75	9.75	10.35	10.12	10.30		10.60	9.10		11.40
	11.30	10.10	10.75	10.34	10.63		10.80	9.55		11.63
	11.53	10.62	11.00		11.20		11.05	10.10		11.88
	11.72	11.18	11.40		11.58		11.30	10.37		
		11.58	11.72		11.90		11.50	10.75		
		11.80					11.80	11.10		
								11.30		

In the preparation of the absorption cells, the method described by Coblentz[3] was adopted. Cell thicknesses of 0.3 mm were used for investigating absorption from 1.00μ to 6.00μ and thicknesses of 0.04 mm for the region between 6.00μ and 12.00μ. A fresh cell was used for each liquid.

The procedure followed was to read the deflections of the galvanometer with the absorption cell in the light path and then with the rocksalt plate in the light path. The ratio of these two deflections was assumed to be the percent transmission of the liquid. Duplicate readings were taken for each wave-length setting and galvanometer zero corrections applied. The slit width was increased from time to time as longer wave-lengths were reached in order to offset the decreasing intensity of radiation of the Nernst glower. The width of the slit ranged from 0.4 mm to 1 mm; 0.5 mm slit width corresponds to about 0.1μ for a wave-length of one μ, to about 0.2μ in the region of 3μ, and to about 0.4μ in the region of 8μ.

[3] Coblentz, Carnegie Inst. Pub. No. 35, 23 (1905).

Absorption measurements between 1.00μ and 6.00μ were repeated with a spectrometer placed at the disposal of the author by the Radiometry Laboratory of the U. S. Bureau of Standards. The apparatus was similar to the one just described except that a fluorite prism was employed in place of the rocksalt one. The absorption curves obtained with this instrument are plotted on the same graphs as those obtained with the rocksalt spectrometer. The positions of the absorption maxima and the whole appearance of the curves measured with the two spectrometers agreed very well. As the wave-length calibration of the fluorite instrument had been checked at the Bureau of Standards, this agreement is a proof that the wave-length calibration of the other is correct too. Furthermore, the agreement between the form of the curves is also a proof that stray radiations do not vitiate the curves to any great extent, as it is very improbable that the stray radiations would be so much alike in both instruments.

In all cases the alkaloids were obtained from the most reliable sources possible and compounds of questionable purity were fractionally distilled.

The alkaloids which oxidized readily were used within a few hours after exposure to air.

Compounds (1), (2), (3), (4) and (9) were provided by Dr. C. R. Smith of the U. S. Department of Agriculture. Compounds (8), (11) and (12) were obtained from Eimer and Amend and purified by fractional distillation. Compound (5) was obtained from the Eastman Kodak Company and Compound (10) from Merck; both were purified by distillation. The author prepared (6) and (7) from Spartine sulphate and arecoline hydrobromide, respectively.

Results

Figs. 2 to 12 and Table I show the results of this investigation. These absorption curves possess some features worthy of mention. They all show to different degrees absorption bands corresponding to N−H, C−H and C−H_2 frequencies at 2.98μ, 3.43μ and 6.88μ respectively.[3, 4] The bands at about 3.25μ, 6.25μ and 6.75μ are probably associated with vibrations of the benzene ring as they appear quite strongly in the absorption spectra of simple benzene derivatives. The weak band at about 6.20μ which appears in

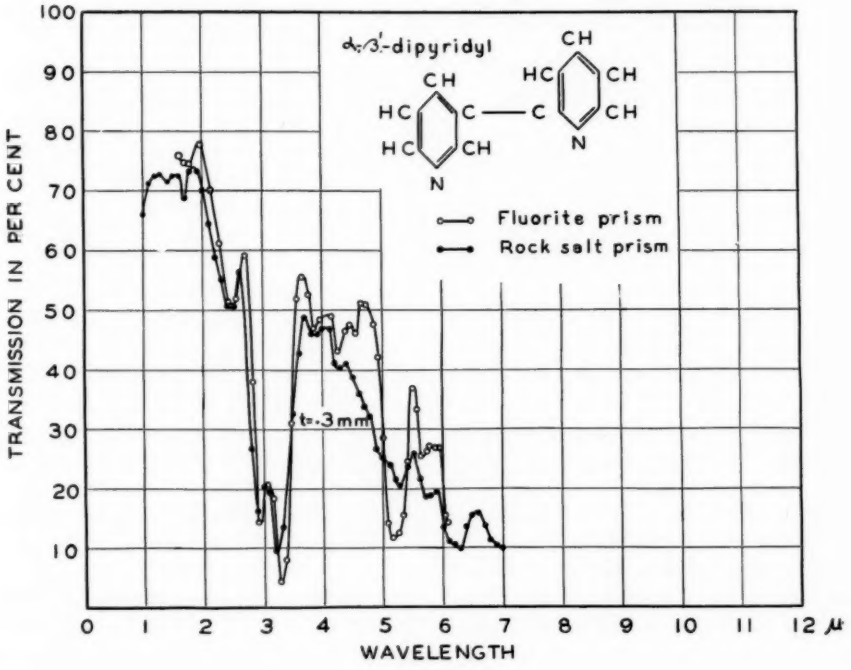

Fig. 2.

most of the absorption curves is probably due to water vapor. (2) and (3) are presumably the same substance, (2) being a plant extract and (3) the synthetic product. It is to be noted that there are small differences in their absorption spectra and that the natural alkaloid is levorotatory while the synthetic product is inactive.

The infrared absorption of (5) and (11) (nicotine and pilocarpine) have already been determined by Spence.[1] His curves have been compared with those of the author. The agreement is good, the author's curves showing perhaps rather better resolution. A number of weak absorption bands appear only in the curve found with the fluorite prism. This is due to the higher dispersion of the fluorite prism in this region.

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[4] Salant, Proc. Nat. Acad. Sci. 12, 74 (1926).

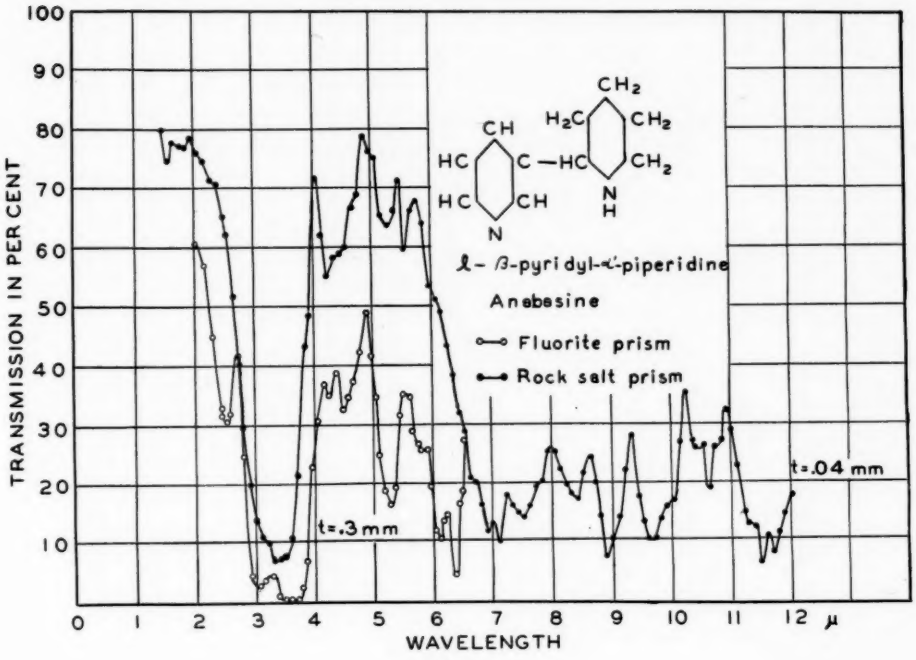
TRANSMISSION IN PER CENT
100
90
80
70
60
50
40
30
20
10
0 1 2 3 4 5 6 7 8 9 10 11 12 μ
WAVELENGTH
CH2
H2C
CH2
CH
HC
C—HC
CH2
HC
CH
N
NH
l- β-pyridyl-α'-piperidine
Anabasine
Fluorite prism
Rock salt prism
t=.3 mm
t=.04 mm

FIG. 3.

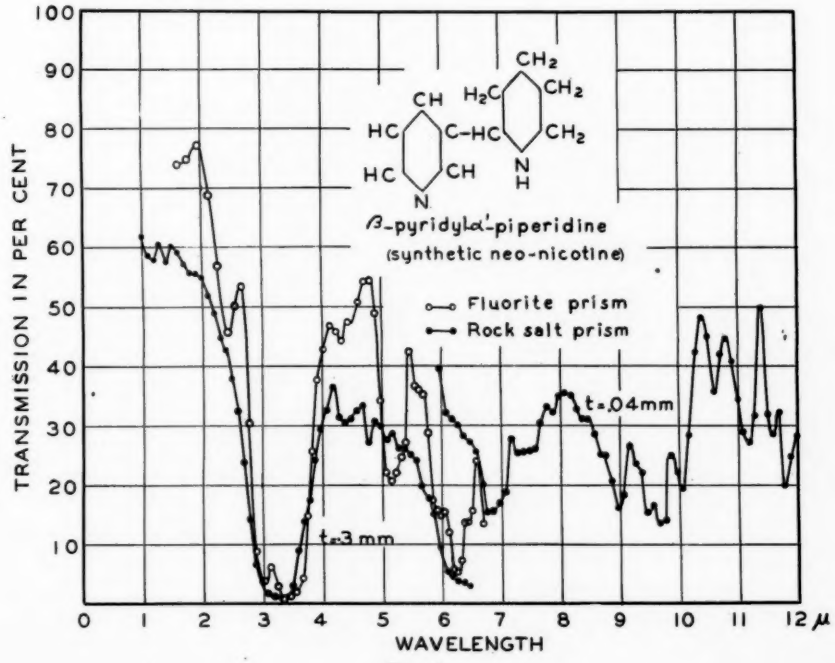
TRANSMISSION IN PER CENT
100
90
80
70
60
50
40
30
20
10
0 1 2 3 4 5 6 7 8 9 10 11 12 μ
WAVELENGTH
CH2
H2C
CH2
CH
HC
C-HC
CH2
HC
CH
N
NH
β-pyridyl-α'-piperidine
(synthetic neo-nicotine)
Fluorite prism
Rock salt prism
t=.04mm
t=.3 mm

FIG. 4.

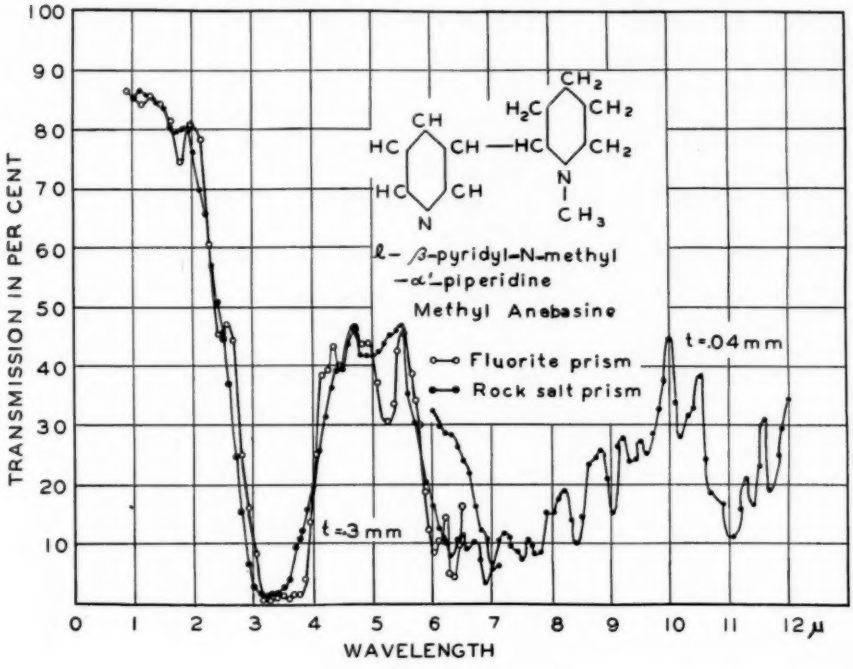
TRANSMISSION IN PER CENT
WAVELENGTH
l- β-pyridyl-N-methyl
-α'-piperidine
Methyl Anabasine
Fluorite prism
Rock salt prism
t=.04mm
t=.3mm

FIG. 5.

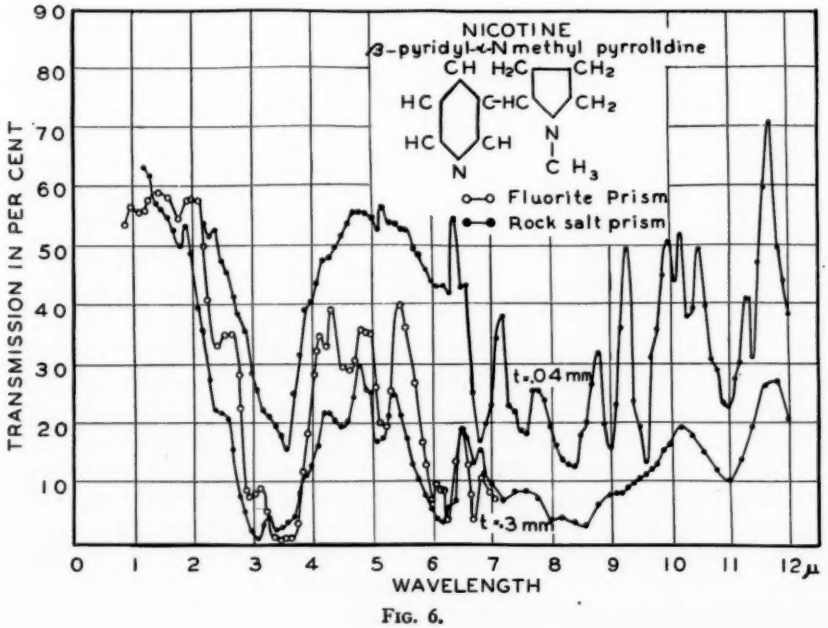
NICOTINE
β-pyridyl-α-N methyl pyrrolidine
TRANSMISSION IN PER CENT
WAVELENGTH
Fluorite Prism
Rock salt prism
t=.04mm
t=.3mm

FIG. 6.

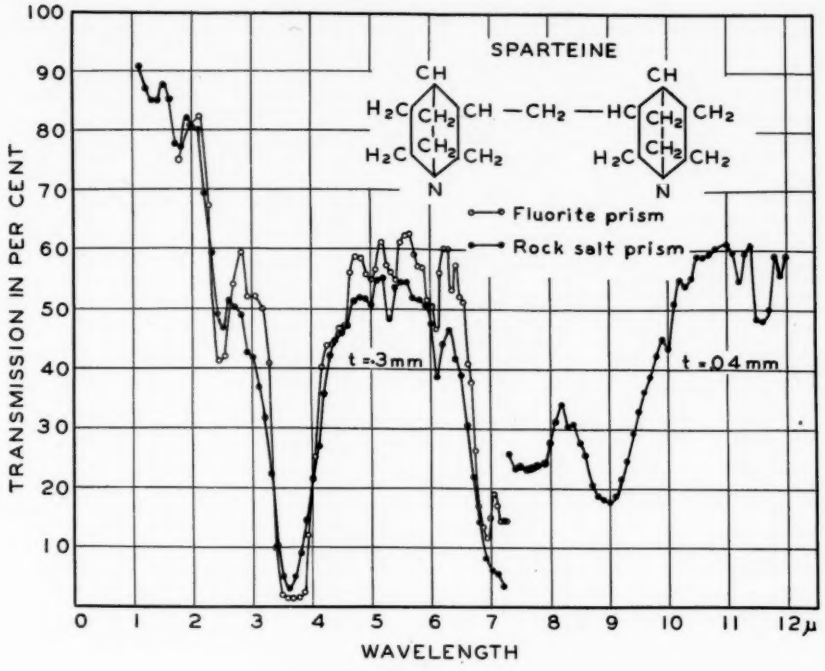
SPARTEINE
Fluorite prism
Rock salt prism
t = .3 mm
t = .04 mm
TRANSMISSION IN PER CENT
WAVELENGTH

FIG. 7.

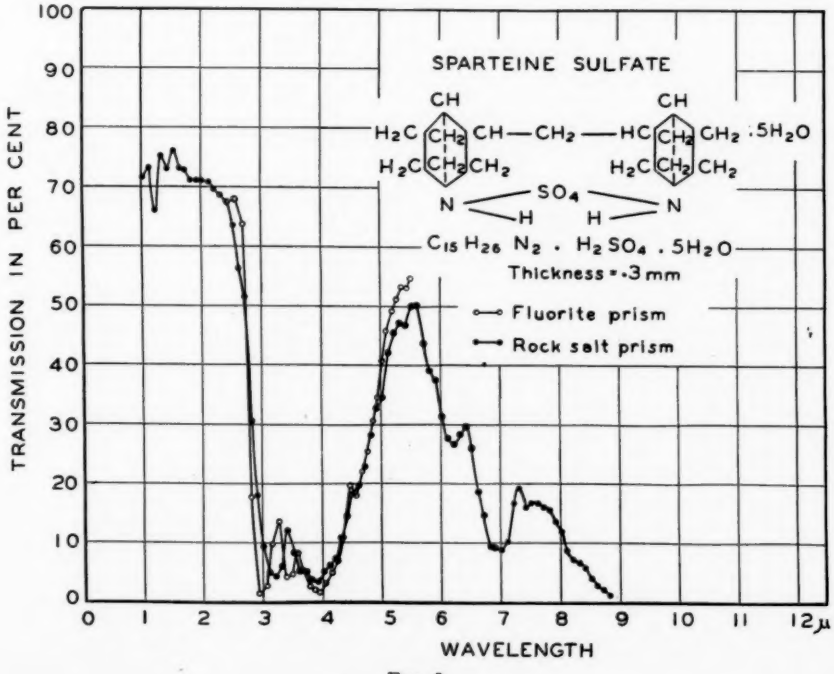
SPARTEINE SULFATE
$C_{15}H_{26}N_2 \cdot H_2SO_4 \cdot 5H_2O$
Thickness = .3 mm
Fluorite prism
Rock salt prism
TRANSMISSION IN PER CENT
WAVELENGTH

FIG. 8.

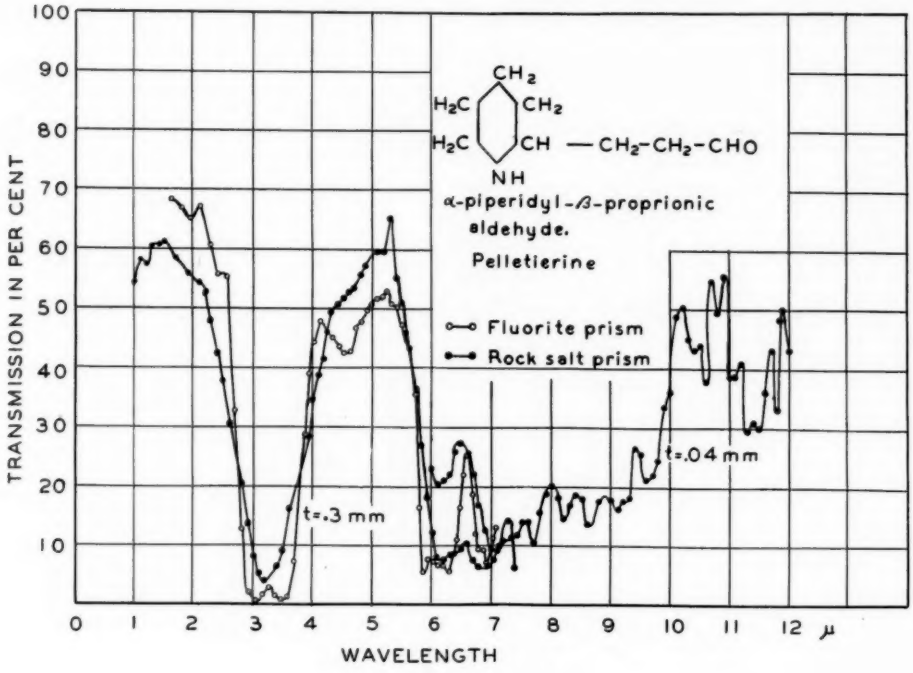
TRANSMISSION IN PER CENT
WAVELENGTH
α-piperidyl-β-proprionic aldehyde.
Pelletierine
Fluorite prism
Rock salt prism
t=.3 mm
t=.04 mm

FIG. 9.

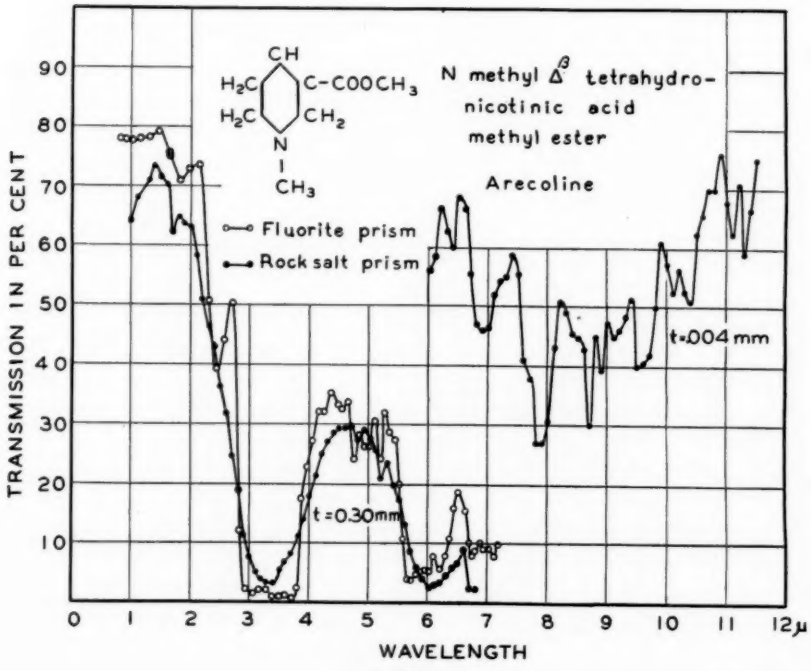
TRANSMISSION IN PER CENT
WAVELENGTH
N methyl Δβ tetrahydro-nicotinic acid methyl ester
Arecoline
Fluorite prism
Rock salt prism
t=0.30mm
t=.004 mm

FIG. 10.

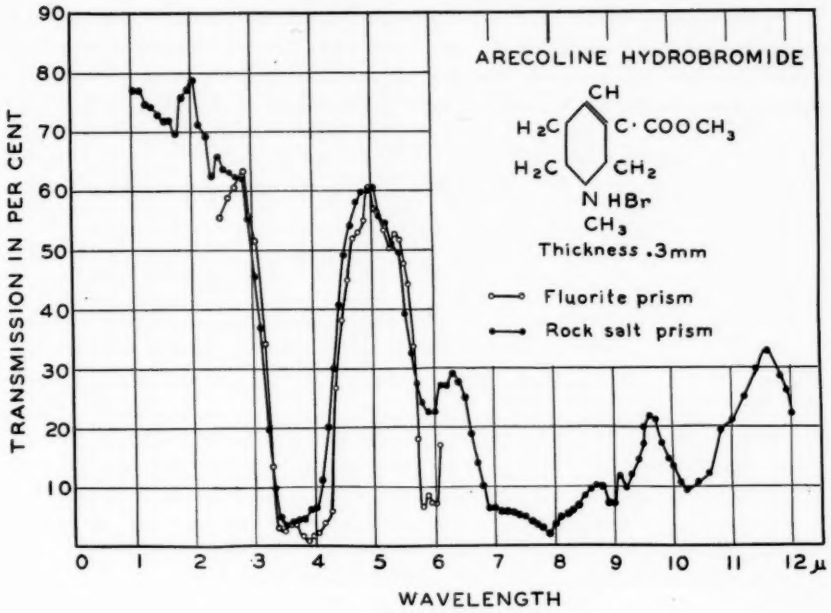
ARECOLINE HYDROBROMIDE
CH
H2C
C·COOCH3
H2C
CH2
N HBr
CH3
Thickness .3mm
Fluorite prism
Rock salt prism
TRANSMISSION IN PER CENT
WAVELENGTH
0 1 2 3 4 5 6 7 8 9 10 11 12 μ
10 20 30 40 50 60 70 80 90

FIG. 11.

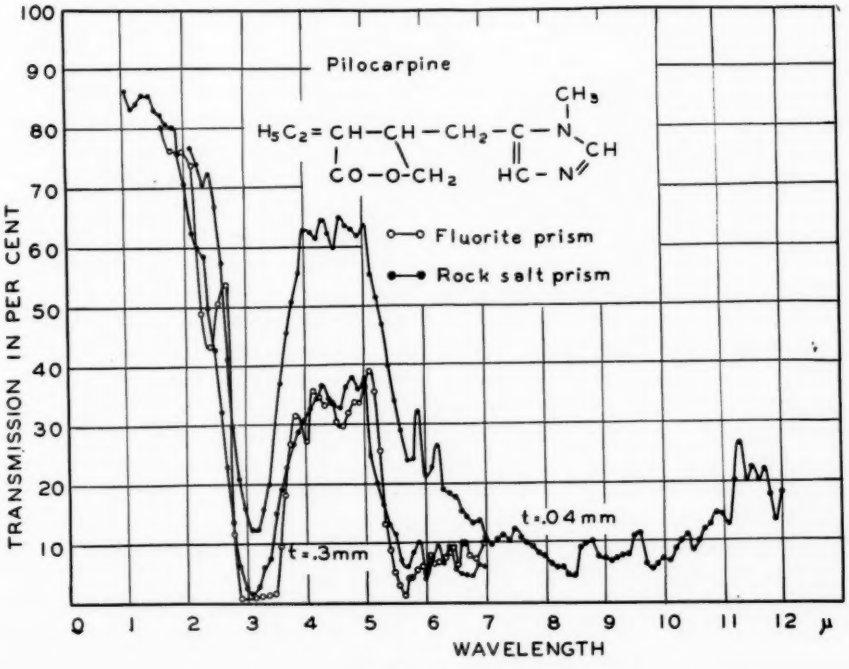
Pilocarpine
CH3
H5C2=CH—CH—CH2—C—N
CH
CO—O—CH2
HC—N
Fluorite prism
Rock salt prism
t=.04 mm
t=.3mm
TRANSMISSION IN PER CENT
WAVELENGTH
0 1 2 3 4 5 6 7 8 9 10 11 12 μ
10 20 30 40 50 60 70 80 90 100

FIG. 12.

ACKNOWLEDGMENT

This experiment has been accepted by the Faculty of the Catholic University of America as a dissertation for the degree of Doctor of Philosophy.

The author wishes to express her gratitude to Dr. George D. Rock and Dr. Leo F. Talbott of the Department of Physics of this University for the many helpful suggestions received during the preparation of this paper. Thanks are also due to Dr. W. W. Coblentz of the U. S. Bureau of Standards, Washington, D. C., for the use of the Radiometry Laboratory, and for the kindly interest shown during the experiment.

A Photographic Method of Measuring the Relative Intensities of Spectral Lines

K. B. THOMSON AND O. S. DUFFENDACK, *University of Michigan*

(Received October 24, 1932)

A method for measuring the relative intensities of spectral lines is described in which a step diaphragm is substituted for the slit of a spectrograph. A continuous source of light then produces on the photographic plate a set of bands over which the intensity of the light varies as the widths of the openings in the step diaphragm. Necessary precautions in the use of the method are noted. Results from this method are compared with those obtained by varying the distance to the source. Possible errors in measurements on relative intensities of spectral lines due to the Eberhard effect and to the use of an intermittent source are mentioned.

THE relative intensities of spectral lines may be measured by comparing the blackening they produce on a photographic plate. The lines cannot be compared directly because the relative blackening depends very strongly on the conditions under which the plate is developed, the type of plate used, the wave-length of the light, etc. If over different areas of the plate the light varies in intensity in a known way, the relative intensities of spectral lines may then be determined by comparing the blackening they produce with the blackening of these calibration areas.

In the present paper, the term "blackening" will refer to the deflection of the galvanometer of a Moll microphotometer from its position when only the clear plate is in the path of the beam to that when a spectral line intercepts the beam. The value of this quantity, obviously, will depend upon the intensity of the lamp used to illuminate the thermopile as well as on the intensity of the spectral line or calibration area. It is sufficient for the measurement of intensity, however, as the lamp intensity may be kept constant while one plate is being run and each plate must be calibrated separately in any case.

Another quantity which is frequently used in intensity measurements is the "opacity." This is defined as the reciprocal of the fraction of the incident light which is transmitted by the plate. This will be practically independent of the intensity of the incident light although it may depend to some extent on its wave-length. For intensity measurements such as those described below this quantity has no advantage over the blackening.

A third quantity which is used is the "density." This is defined as the logarithm (usually to the base 10) of the opacity. It may be calculated from microphotometer measurements, or it may be measured directly by means of a properly calibrated photometric instrument as, for example, the Gaertner microdensitometer. The density will be a function of a number of parameters, including the intensity of illumination and the time of exposure. The reciprocity law assumes that intensity and time of exposure occur only as a product. If we call this product the exposure, the density may be expressed, over a considerable range of exposures, by the relation $D=D_0+\gamma \log E$. The slope, γ, of the straight line portion of the curve obtained by plotting density against exposure is called the contrast of the plate. The value of this will depend upon various factors, such as time of development, type of emulsion, etc. These curves are the "characteristic" curves for the plate, and are sometimes called the Hurter and Driffield or H. and D.[1] curves.

More exact experiments have shown that the assumption that intensity and time of exposure occur only as a simple product is not justified. Schwarzschild finds that the exposure E is given by $E=It^p$ where p is a constant not much different from 1 and I and t are, respectively, intensity of illumination and time of exposure. It is now well known that p is not a constant. Others have found more complicated relations.[1] This failure of the reciprocity law makes a

[1] F. E. Ross, *The Physics of the Developed Photographic Image*, D. Van Nostrand Company, New York.

series of timed exposures unsatisfactory as a means of calibrating a plate.

Fig. 1 shows a curve obtained by plotting the blackening of a plate against the logarithm of the intensity. It will be seen from this curve that,

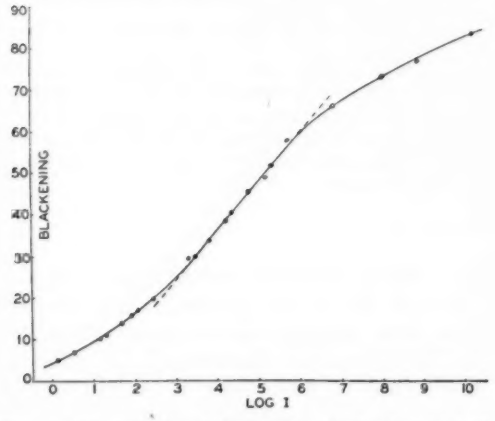

FIG. 1. The relation between the blackening and the logarithm of the intensity of the light.

(over a certain range of intensities) the blackening obeys a law similar to that followed by the density. For this range, we can express the blackening by the relation $B=B_0+A \log I$. The range of intensities over which this will hold is smaller than the range over which the density obeys a similar law, and the straight line portion of the blackening curve comes at lower intensities—corresponding to those on the curved lower portion of the density curve. These lower intensities were found more satisfactory for work with the Moll microphotometer, because of the greater difference in galvanometer deflection for a given difference in opacity. The relative intensities of spectral lines on the same plate have been determined both by measurement of the densities of the lines and of their blackenings. The results were in every case in complete agreement within the limits of experimental errors. Repeated measurements were as consistent in one case as in the other.

A number of methods have been devised for putting the calibration marks on the plates. Hansen[2] used a "step-diaphragm" in conjunction with a spherical lens and a cylindrical lens. The lenses were so placed that an astigmatic image of the diaphragm was thrown on the plate so that there was sharp focus in the vertical plane while the light was spread into a parallel beam in the horizontal plane. The result was a series of parallel bands in each of which the illumination was proportional to the width of the corresponding opening of the diaphragm. A variation of this method consists in allowing the astigmatic image to fall on the slit of a spectrograph, with a source giving a continuous spectrum to illuminate the diaphragm. This gives a series of continuous spectra with intensities proportional to the widths of the openings.

Another method is that of Ornstein[3] who illuminated the slit of a spectrograph with continuous radiation and took exposures with various widths of the slit. The intensity of illumination of the plate is proportional to the slit width, so long as too great widths are not used and the source gives a fairly uniform continuous spectrum.

The method used by the authors might be considered as a combination of the two methods given above. It was first proposed by Ornstein[4] and tested by Read and Johnson.[5] A step diaphragm was employed, but the widths of the steps were smaller than those used by Hansen. Six steps were used, the widest of which was about three millimeters. Each step was approximately 1.5 times as wide as the next smaller one. The slit of the spectrograph was opened wide and the diaphragm placed directly in front of it; in other words the diaphragm was substituted for the slit. The diaphragm was then illuminated by a source of light giving a continuous spectrum. The result of this method is a continuous spectrum with six strips of different intensity, as shown in Fig. 2.

The size of the source of light used is an important factor in this method. Two possibilities are open to choice. A very broad source may be used close enough to the diaphragm so that light from any point of the diaphragm completely fills the lens of the spectrograph, or a small source may be used sufficiently far away that all the

[2] Hansen, Zeits. f. Physik **29**, 356 (1924); von Hippel, Ann. d. Physik **80**, 672 (1926); van Cittert, Zeits. f. Physik **73**, 249 (1931).

[3] Ornstein, Phys. Zeits. **28**, 688 (1927).

[4] Ornstein, Proc. Phys. Soc. (London) **37**, 337 (1925).

[5] Read and Johnson, Phil. Mag. **11**, 1152 (1931).

light that passes through the diaphragm will also pass through the lens. The authors have chosen the second type of source as it is easier to set up. The first requirement might be fulfilled by the use of a uniform diffusing screen close to the diaphragm, but perfect uniformity is difficult to attain.

One source used was a condensed spark between aluminum electrodes in hydrogen at atmospheric pressure. Some aluminum lines appear in the spectrum of this spark but they are widely spaced and did not interfere seriously with the measurements. The aluminum lines appear in the calibration pattern simply as uniformly illuminated images of the diaphragm superimposed on the parallel strips of different intensity due to the continuous background. Their appearance is shown in Fig. 2.

Another source which was used was a low-voltage arc in hydrogen, with a tungsten filament as cathode and a tungsten cylinder as anode.

FIG. 2. Intensity calibration pattern produced by a condensed spark between aluminum electrodes in hydrogen at atmospheric pressure and a step diaphragm mounted at the slit of a spectrograph. The uniformly darkened patterns are due to spectral lines in the source.

This gives a continuous spectrum without lines, except for the Balmer series. The continuous spectrum of hydrogen extends over the whole range in which measurements of intensity can be made with ordinary plates and below the region which can be covered with a tungsten lamp. It is thus very suitable for measurements in the ultraviolet.

This method has several advantages over the other methods given above. Its chief advantage over Ornstein's method of widening the slit is that all the exposures are made at the same time so that no special precautions are necessary to keep the intensity of the source constant. For the shorter wave-lengths, where the light from the tungsten filament lamp is too weak, this is an important advantage. It has the advantage of greater simplicity over the method of Hansen since the external optical system is dispensed with. It also obviates difficulties due to chromatic aberration in the external system. The simpler method of throwing the astigmatic image directly on the photographic plate is unsatisfactory because all wave-lengths are superimposed and only a limited range may be used if sharp focus is to be attained. Moreover, over certain wave-length regions the value of the constant A in the relation between blackening and log I varies rapidly with the wave-length of the light used, and it is therefore important to have the calibration made over the whole range of wave-lengths to be compared. The methods using the spectrograph are the only ones giving this complete calibration.

One disadvantage of the method is that there is a considerable amount of overlapping of different wave-lengths in the light from the wider openings. With a Hilger E2 quartz spectrograph and a three millimeter opening, the overlapping amounts to about 150 Angstrom units in the wave-length region at 3000A. In a wave-length region in which the value of the quantity A varies rapidly with the wave-length, this is a serious disadvantage. It can be largely overcome by the use of an instrument of greater dispersion. Fortunately, it is possible to find plates for which the value of the quantity A changes very little over a considerable range of wave-lengths. Fig. 3 shows the relation for the range 2300–5000A between wave-length and A for an Eastman Polychrome plate. It may be noted that the value of A does not change appreciably for this plate between 2400 and 3800A.

In Fig. 4 is shown a comparison of the results from the step diaphragm with those obtained by

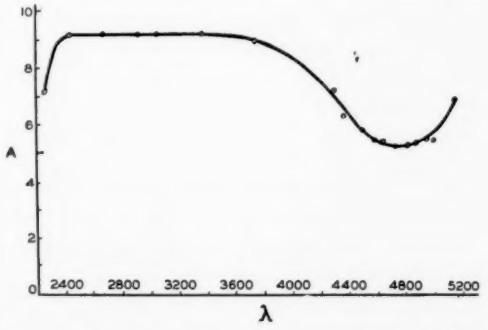

FIG. 3. The relation between the slope, A, of the blackening-log I curves and wave-length of light for an Eastman "Polychrome" plate.

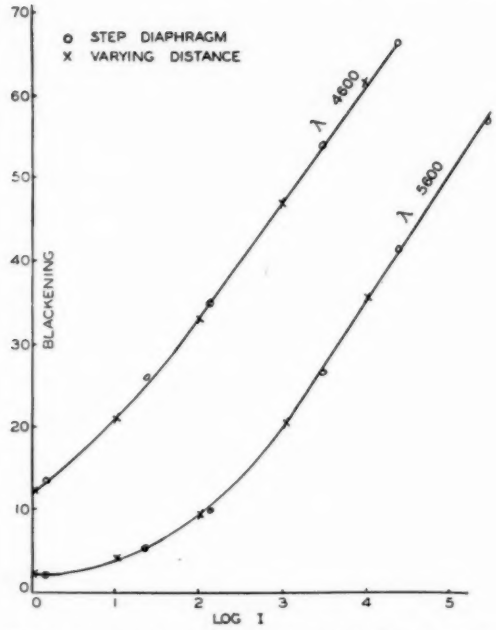

FIG. 4. A comparison of the results obtained with the step diaphragm and by varying the distance to the source.

varying the distance to the source of light. The distance to the incandescent lamp source was so great that the inverse square law could be assumed to hold. The measurements were made on plates taken with a Hilger E1 spectrograph with a glass prism giving a dispersion of about seven Angstroms per millimeter at 4500A.

There are several difficulties which affect this as well as all similar methods of measuring intensities. One of these is the Eberhard effect, an increase in the density of a sharp image just at the edge of the image. We have found that the effect is not large if the developer is agitated continually during the development of the plate. Walenkov[6] has made a study of this effect and concluded that it does not introduce serious error.

A much more serious error is introduced by the effect of intermittency of the source. The value of A is quite different when the source of light is intermittent than when it is steady. This effect has been extensively studied by a number of spectroscopists.[7] In an investigation of the enhancement of certain terms in the spark spectra of metals excited by impacts of the second kind with ions of the rare gases,[8] a comparison was made of the intensities, in this type of excitation and in a mildly condensed spark, of lines from the levels concerned relative to the intensity of a line not affected by the rare gas. The intensity calibration pattern, like that in Fig. 2, was put on the plates by means of a step diaphragm illuminated by a spark excited in a 60-cycle a.c. circuit. The same circuit was used to excite the spark between the electrodes of the metal under investigation. This source was, of course, intermittent, whereas the source used in the excitation by impacts of the second kind was steady. It was found that lines from the same level were enhanced different amounts in the spectrum of the metal excited by impacts of the second kind relative to the same lines excited in the spark. The enhancement was greater for strong lines than for weak lines.

Any variation in the enhancement of lines from a given level is difficult to explain. If the population of the level is increased in anyway, it would be expected that the intensities of all the lines coming from this level would be increased in the same ratio. The discrepancy was traced to the intermittency effect, and, in later work, a steady source was used to illuminate the step diaphragm to measure the relative intensities of lines in the steady source and the intermittent spark in hydrogen when the lines in the spectrum of the spark were compared. It was then found that all lines from a given level were enhanced equally. A low-voltage arc in hydrogen was used as the steady source of continuous light for the illumination of the step diaphragm. A steady source should be used to illuminate the step diaphragm when the spectrum of a steady source is examined, and an intermittent source when an intermittent source is to be examined.

The authors wish to express their appreciation of the very fine work of Mr. Herman Roemer who designed and made the metal step diaphragm used in this work.

[6] Walenkov, Zeits. f. Wiss. Phot. **27**, 236 (1930).

[7] Weber, Ann. d. Physik **45**, 801 (1914); Howe, Phys. Rev. **8**, 674 (1916); Baker, Optical Society Convention, Proceedings, 1926, p. 238; Davis, Bur. Stand. Sci. Pap. No. 528, 1926; Twyman, Trans. Op. Soc. **31**, 1929; O'Brien, Phys. Rev. **33**, 640 (1929); **37**, 471 (1931); **41**, 387 (1932).

[8] Duffendack and Thomson, Phys. Rev. **43**, 106 (1933).

The Spectra of Potassium and Sodium in the Mercury Arc

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(Received October 7, 1932)

I. INTRODUCTION

IN a recent paper the authors[1] described a simple mercury arc in Pyrex which, from the standpoint of ease of construction, intensity, size and long life, proved very satisfactory. As a further development it was decided to try introducing various elements into the mercury with the hope of improving the results of previous amalgam lamps and possibly constructing a series of such lamps that could be used for standard experiments in spectroscopy. A number of elements have been tried with varying degrees of success; however, the work thus far has been mainly with the alkali metals. It is to be expected that one would obtain greater spectral intensity from the alkali metals because of their low boiling temperatures and ionization potentials. The spectra of these metals are of great importance for introductory laboratory work in spectroscopy.

Quite a number of papers describing various forms of alkali metal lamps and their spectra have been published. L. Arons[2] was among the first to publish work of this nature. He has constructed numerous mercury-amalgam lamps but since soft glass was used it was found necessary to cool the lamps with water. This so greatly reduced the temperature of the arc that lines of potassium and sodium did not appear even with a current of twenty amperes. A later amalgam lamp of E. Gumlich[3] made of quartz gave somewhat better results, however, it appears that he did not try mercury-alkali metal amalgams. F. H. Newman[4] has contributed several papers on alkali metal lamps, all of which were made of quartz with wax or lead seals and were not of a simple design that could be sealed off and used for general routine laboratory work. None of Newman's alkali arcs contained mercury as one of the components of the amalgam. R. J. Strutt[5] describes a quartz alkali metal arc which works satisfactorily as a research lamp but is of little value for general use.

This paper is an account of the very satisfactory results obtained with potassium and sodium. As a matter of convenience specific reference will be made to the work with potassium and mercury which, however, will apply equally well to the sodium-mercury combination. Identical lamps containing various percentages of potassium in mercury were constructed and the character of the discharge and spectra studied.

II. PREPARATION OF THE LAMP

As mentioned above the design of the lamp already has been described. The method of introducing the potassium, and evacuating is very important and will be given in some detail. It is necessary that the glass, mercury and potassium be perfectly clean and as nearly free from occluded gases and water vapor as possible. In order to remove gases and successfully introduce the potassium the following procedure was adopted. First, the empty lamp was evacuated. For some time during this period a Bunsen flame was applied and the glass kept at a temperature just below its softening point. Following this the desired amount of chemically pure mercury was introduced and boiled vigorously in the vacuum to eliminate gases and water vapor. Upon removing the lamp from the pump again, previously prepared potassium was dropped, without delay, into the connecting tube as shown in Fig. 1a. After a third short period of evacuation the flame was applied gently to the portion of the tube containing potassium. The

[1] Isay Balinkin and D. A. Wells, R. S. I. 3, 388 (1932).
[2] L. Arons, Ann. d. Physik 58, 73 (1896); 23, 176 (1907).
[3] E. Gumlich, Ann. d. Physik 61, 401 (1897).
[4] F. H. Newman, Proc. Phys. Soc. 33, 70 (1921); Phil. Mag. 44, 944 (1922); 45, 181 (1923); 45, 293 (1923); 48, 159 (1924); 47, 603 (1924).
[5] R. J. Strutt, Proc. Roy. Soc. A96, 272 (1920).

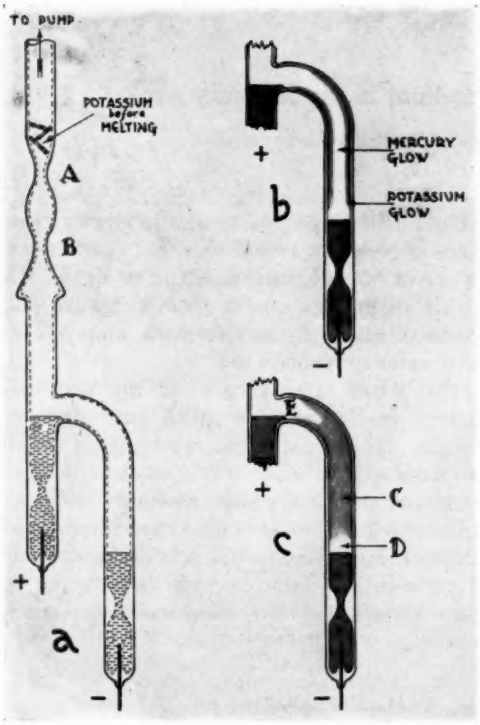

FIG. 1. (a) Construction of lamp, (b) partial potassium glow, (c) full potassium glow.

melted potassium ran down through the constrictions *A* and *B* into the lamp, leaving behind any sludge that may have been present. After boiling the mercury to mix it thoroughly with the potassium, the lamp was sealed off at *B*.

The potassium was prepared by cutting it into narrow strips under the surface of petrolic ether, as suggested by Mr. J. Gray. By manipulating the potassium in ether all kerosene is thoroughly removed and even though it is still wet when introduced into the lamp, the remaining ether is easily pumped off.

III. The Pump and Spectrograph

A Cenco Hyvac pump, producing a vacuum of about one micron was used throughout the work. The lamps were connected to the pump by means of heavy rubber vacuum tubing. A glass trap in the vacuum line prevented mercury and other metallic vapors from entering the pump.

The spectrograph[6] used for this work consisted of a concave grating (Wallace replica, 15,000 lines per inch, 1060 mm focal length) mounted permanently in a light tight sheet metal housing. An adjustable slit and curved film holder were built directly into the metal housing opposite the grating. The position of the spectrum with respect to the film could be adjusted by changing the tilt of the grating.

IV. Character of the Discharge

Lamps of identical construction but containing from about one-half to three percent of potassium have been investigated. In no case is there an appreciable indication of the presence of potassium at the instant the lamp is started. However, as the lamp heats up a definite red potassium glow begins to appear. If the percentage is small the potassium glow takes the form of a definite layer about one to two millimeters thick lining the inside walls of the tube as shown in Fig. 1b, the center of the tube remaining filled with the usual mercury discharge. The inner core of mercury and surrounding potassium glow are quite sharply separated as can easily be seen by observing the lamp through dark glasses.

When the percentage of potassium is about two, the mercury core disappears and the tube becomes completely filled with potassium glow except for a small layer at the surface of the mercury, *D*, and in the space, *E*, Fig. 1c. The manner in which the glow builds up is of interest. After the lamp has been operating for about two minutes the glow begins to appear around the inside walls of the glass as described above, then as the temperature of the lamp further increases the core of mercury discharge gradually decreases in diameter and within a few seconds the lower end of the core breaks away from the space, *D*, and is apparently pushed up the tube to *E*.

It is found that the full potassium glow is somewhat unstable and will not be maintained continuously unless the current and voltage are carefully regulated. For one of the lamps the required current was 1.32 amperes at 38.5 volts across the terminals of the lamp. A small decrease

[6] We are greatly indebted to the Central Scientific Company of Chicago for placing at our disposal their new replica grating spectrograph.

in temperature such as may be brought about by a slight breeze over the lamp will cause the potassium glow to disappear. The disappearance takes place in just the reverse order in which it builds up.

The above remarks regarding the character of the discharge apply to the lamp shown in Fig. 1. It should be stated, however, that a number of lamps having various shapes and sizes were tried with rather unsatisfactory results. It was found quite difficult to obtain the full potassium glow with larger lamps except by heating with a Bunsen flame and even then the discharge was not steady.

Unfortunately all lamps become darkened on the inside after burning for a time. However, for spectroscopic work this is not as objectionable as it might seem since the time of exposure for a spectrogram is a matter of seconds or minutes, while the total period which the lamp will burn without serious darkening is a number of hours.

V. Spectra Obtained

The three spectrograms in Fig. 2 show the spectral lines obtained (a) just after the lamp is started (exposure 25 sec.); (b) with partial potassium glow (exposure one min.); and (c) with full potassium glow (exposure four min.). It will be noticed that (a) shows only mercury lines, (b) potassium and mercury, and (c) strong potassium lines with mercury lines greatly suppressed. The spectrum of full potassium glow is very striking. Even with a small direct vision spectroscope, lines in the principal, sharp and diffuse series can easily be distinguished, all mercury lines being very weak. Lines of the sharp and diffuse series are distinguishable to at least the tenth component as is shown in Fig. 3. (First two components fall in the infrared and red region of the spectrum.) For convenience the lines have been separated into the various series. The mercury lines present are also shown separately. It will be observed that the *D* lines of sodium are quite strong. Close examination shows many other sodium lines all of which are, of course, due to the potassium containing a small percent of sodium.

Fig. 4 is a spectrogram taken with regions, *C* and *D*, Fig. 1c placed very close to the long slit of the spectrograph. The lower portion of Fig. 4 shows the spectrum of *D*, while the upper part shows the lines from the full potassium glow. It is seen that the mercury lines from *D* are very strong but gradually fade out almost completely

Fig. 2. Spectrograms of K–Hg amalgam lamp. (a) At start, (b) partial potassium glow, (c) full potassium glow.

Fig. 3. The spectrum of potassium in mercury showing various potassium series.

FIG. 4. Spectrogram showing change in character of spectrum from regions *D* to *C* of Fig. 1c.

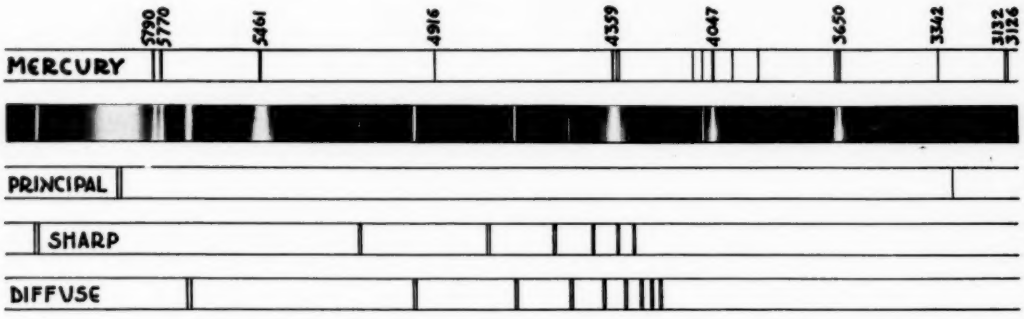

FIG. 5. The spectrum of sodium in mercury showing various sodium series.

in the region *C*. This suppression of the mercury discharge is of considerable interest since the percent of potassium is so small.

The experimental procedure and general results with sodium-mercury lamps were the same as for potassium. Fig. 5 is a spectrogram of the full glow from a lamp containing about two percent of sodium. The lines are quite intense and can easily be separated into the various series as shown by the figure.

VI. Discussion of Results

The results of these experiments show that it is quite possible to construct very satisfactory mercury-potassium and mercury-sodium amalgam lamps if proper precautions are taken as regards percent of potassium or sodium, dimensions, wattage input and evacuation. If the watts consumed by lamp are carefully controlled, a full potassium or sodium glow is established with greatly reduced intensity of the mercury lines. As seen through dark glasses, the alkali metal seems to carry the entire discharge except in the regions, *D* and *C*. So great is the reduction in intensity of the mercury lines that only about six are present on the spectrogram of Fig. 3, notwithstanding a long exposure of four minutes. Even the mercury green line is very much less intense than the lines of the third component of the sharp and diffuse series of potassium. The spectral series, as seen with only a hand spectroscope, would be most convincing evidence of the simple series relationships, to an elementary student of spectroscopy. In the case of potassium a definite region of continuous radiation can be observed at the limit of the sharp and diffuse series (does not show in the reproduction).

It is rather easy to construct these lamps and it is hoped that they may be useful especially for introductory laboratory work in spectroscopy. As previously mentioned, blackening is at present an unavoidable feature but it is not sufficiently fast to spoil the usefulness of the lamp.

Experiments are now under way with the other alkali metals and it is hoped that we may give a report on them at an early date.

Color in Films of Sputtered Tin

CLARENCE J. OVERBECK, *Northwestern University*

(Received December 5, 1932)

Films were sputtered on glass from circular tin cathodes. These films, when produced in air or oxygen and viewed with monochromatic light, show alternately light and dark rings; in white light they show several cycles of the colors of the visible continuous spectrum, similar in appearance to Newton's rings. In the formation of a set of rings the center gradually passes through a cycle of colors of increasing wave-length to the red. The red center then merges into blue and the cycle is repeated. With the appearance of each new center color, all preceding colors move outward and form surrounding rings. The rate of growth of a set of rings depends on the sputtering conditions. Under proper conditions, the change of color of the center and the addition of another set of color rings takes place with definite regularity. These colors are believed to be due to an interference effect produced by the variation in thickness of the film layer. This layer is probably stannic oxide. Films produced in nitrogen are opaque brown deposits. Tests indicate the material of these films to be a tin-nitrogen compound. Heating such a film in oxygen produced a nearly transparent color film similar to those sputtered in oxygen or air. Films produced in hydrogen have mirror surfaces of high reflecting power.

INTRODUCTION

THIS investigation was undertaken to study the cause and nature of the color phenomena observed in thin films deposited on glass by cathodic sputtering of tin.[1] It is generally accepted that the usual laws of optics do not explain certain color phenomena such as the surface color produced by the gradual heating of bright steel, of films of alkali metals deposited by distillation in exhausted glass bulbs,[2] or the colors of feathers, butterflies, etc.

Few references to color series in sputtered films appear in the literature.[3] Ingersoll and DeVinney[4] obtained colored films of this type by sputtering nickel on a plate cooled by liquid air. They found that the colors were dulled when the thin films were immersed in a liquid of low refractive index (water), and were completely destroyed in an optically denser liquid (carbon bisulphide). The original colors reappeared when the plates were removed from the liquids and washed. They explain this change in terms of Wood's theory (i.e., the colors are due to a type of resonance phenomena taking place in the interstices between the particles of the film). Thick films did not show this effect as definitely. Dreisch and Rütten[5] consider the colors of their gold film as being due to a difference of structure such as a modification from an amorphous to a crystalline phase. Edwards[6] concludes that the production of color in thin sputtered films is probably due to an interference effect.

APPARATUS AND METHOD

The apparatus was made of Pyrex glass assembled as shown in Fig. 1.

A steady potential, variable from 1800 to 2600 volts, was applied between the aluminum anode, D, and the tin cathode, F (2 cm in diameter and 2 cm long). The cathode was placed in a Pyrex cup with its surface flush with the top of the cup. The deposit formed on a Pyrex plate, E (3 cm wide and 45 cm long). The distance between cathode and plate was adjustable and held by an electromagnet acting on a glass-enclosed piece of soft iron, M. The deposit plate could be drawn back and forth in the side tubes by a second electromagnet. This permitted making from six to ten deposits before blowing out the end of the side tube to remove the deposit plate. The sputtering chamber was separated from the remainder

[1] Bockstahler and Overbeck, Phys. Rev. **37**, 465 (1931).
[2] R. W. Wood, Phil. Mag. **38**, 98 (1919).
[3] H. Fritze, Ann. d. Physik **47**, 763 (1915). H. W. Edwards, Phys. Rev. **33**, 463 (1929).
[4] Ingersoll and DeVinney, Phys. Rev. **26**, 86 (1925).
[5] Dreisch and Rütten, Zeits. f. Physik **60**, 69 (1930).
[6] H. W. Edwards, Phys. Rev. **38**, 166 (1931).

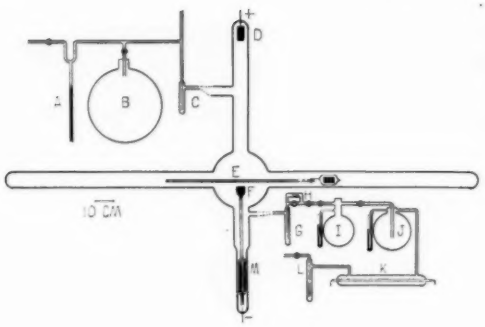

FIG. 1.

of the system by liquid air traps, *C* and *G*. A McLeod gauge was attached above *C*. A 12 liter bottle, *B*, was placed in the system to stabilize the gas pressure. This added volume reduced the pressure variation caused by the vigorous "clean-up" action which was especially large at the beginning of a run. A high-vac pump was attached beyond the mercury cut-off, *A*. The lower right-hand corner of Fig. 1 shows the gas purifying chambers. Water vapor, carbon dioxide, and oxygen were removed from the incoming gas by phosphorus pentoxide in *J*, sodium hydroxide in *L*, and hot copper gauze at *K*. The gas was finally collected for use in flask, *I*, from which it could be admitted into the sputtering system by either of two methods: (1) A capillary opening at *H* permitted a constant flow of fresh gas through the system. With the pump in operation, proper adjustment of the pressure in *I* gave any desired pressure in the system. (2) Known quantities of gas could be admitted periodically by means of the stopcocks at *H*.

The tin used for the cathode was of c.p. quality. The gas content and surface oxide of the cathode were reduced by shaking the molten tin and then allowing it to solidify in a partial vacuum.[7] The cathode was cut out of the interior of this block to fit the Pyrex cup.

FILMS SPUTTERED IN AIR

Films sputtered in dry air were almost transparent and showed very brilliant colors by reflected light and the complementary colors by transmitted light. Watching the formation of a deposit revealed a gradual color change as the deposition progressed. The center of the deposit changed color corresponding to increasing wavelengths. As each new center color appeared, the preceding colors moved outward to form rings of color. When the range of the spectrum was completed with red at the center, this red merged into blue and the cycle of colors repeated. After several such cycles, the spectral series was no longer complete; certain colors decreased in intensity and others became more pronounced. Some plates showed as many as sixteen cycles which appeared as light and dark rings by reflected sodium light. Fig. 2, a photograph made by reflected monochromatic light, of three deposits at different stages, gives an idea of the progressive growth. Deposit 2a, shows two dark rings and a center just becoming clear to form the third ring; 2b, shows the beginning of the fourth ring as a dark center; while in 2c, the fourth ring has cleared and a fifth ring is just starting. If the sputtering process was stopped for a while, and then started again, the order of color formation continued as though no interruption had taken place.

In general the outline of the deposit was similar to that of the cathode surface. All films made from cathodes ranging from 1 to 9 cm in diameter showed colors; however, the central portions of the larger deposits were less brilliantly colored than the edges. The curvature of a smooth cathode surface did not noticeably change the character of the deposit except that in the case of concave surfaces the central portion of the film was burned off because of the heating of the focussed cathode particles.

Frequently the discharge became unstable, giving rise to a sudden high-current density which pitted the cathode surface and produced a granular metallic deposit on the plate. A microscopic examination revealed that these metallic particles were of two general forms. The largest and smallest particles were of a rough

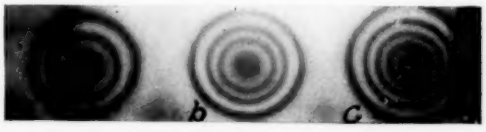

FIG. 2.

[7] P. W. Bridgman, Proc. Amer. Acad. Arts and Sci. **60**, (6) 308 (1925).

spherical shape. By focussing on different parts of the largest pieces of metal, it appeared that they had been flattened on striking the deposit plate, which indicated considerable velocity of impact and heating. The intermediate size particles were made up of torus-like forms heavier on one side. In general, the heavy side of the torus was nearer the center of the deposit. For the larger masses of this kind, the thin part of the figure was open so as to form a horseshoe. The metallic nature of the deposit might be explained by the fact that the particle, rapidly deposited, was of large size and therefore its combination with gas molecules would not be favored. This was substantiated by the fact that continued sputtering with low-current density after such a metallic layer had been set down resulted in a color formation showing through the spots which were not covered by the heavy deposit. In this case the color rings were much distorted, depending on the rough features of the cathode.

TABLE I. *Plate 157.*

Time	Pressure mm Hg	Current m.a.	Number of rings
9:52:00	0.089	3.8	
9:52:30		3.4	
9:53:00		3.0	
9:53:30		2.2	
9:54:00		2.0	
9:54:45	0.086	1.7	
9:56:00		1.5	
9:56:30		1.4	1
9:57:00	0.084	1.4	
10:00:00	0.085	1.3	2
10:05:00	0.088	1.3	3
10:08:00			4
10:10:00	0.085		
10:12:00			5
10:15:00	0.085	1.2	
10:16:00			6
10:20:00	0.086	1.2	7
10:23:30			8
10:25:00	0.084	1.2−	
10:27:00			9
10:30:00	0.085		
10:31:00			10
10:35:00	0.090		11
10:39:00			12
10:40:00	0.088		
10:45:00	0.084	1.1	
10:50:00	0.086		15
10:52:00	end of run		

TABLE II. *Plate 158.*

Time	Pressure mm Hg	Current m.a.	Number of rings
9:03:00	0.091	4.4	
9:03:15		4.0	
9:03:30		3.4	
9:04:00		3.0	
9:04:30		2.2	
9:05:00	0.093	1.6−	
9:07:00			1
9:10:00	0.089	1.5	
9:11:00			2
9:14:30			3
9:15:00	0.086	1.4	
9:18:00			4
9:20:00	0.085	1.3	
9:21:30			5
9:25:00	0.084		6
9:29:30			7
9:30:00	0.086	1.3	
9:33:00			8
9:35:00	0.085	1.2	
9:37:30			9
9:40:00	0.085	1.2	10
9:44:00			11
9:45:00	0.090	1.2	
9:48:00			12
9:50:00	0.086	1.2	
9:52:00			13
9:54:00	0.089	1.2−	
9:56:00			14
9:58:00	0.088		
10:01:30			15
10:02:00	0.084	1.2	
10:03:00	end of run		

Several runs were made with a discharge current (7 to 10 m.a.) sufficiently large to keep the cathode surface always in a molten state. Insofar as could be detected, there was no dif-

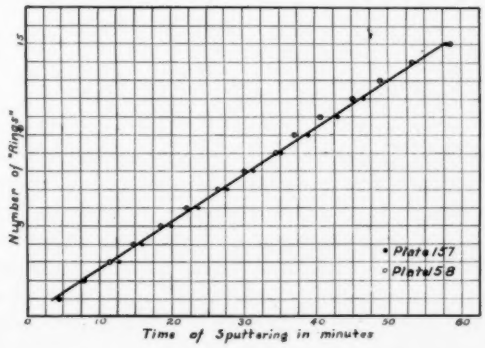

FIG. 3. Rate of growth of color cycles in dry air.

ference in the appearance of the deposit obtained from this and the deposit obtained from the solid surface.

The cathode to plate distance for maximum rate of growth of the color cycles was 8 to 10 mm. Since the color change was gradual, it was impossible to assign a definite time to the appearance of any particular color. The time of the beginning of a dark central ring, when the film was viewed by sodium light, was much more definite. The time of the appearance of consecutive rings for plates 157 and 158 are given in Table I and Table II, and are shown graphically in Fig. 3. The sputtering conditions for both plates were an atmosphere of dry air and a cathode to plate distance of 8.5 mm. A considerable quantity of gas always disappeared during the sputtering process. Approximately 0.0012 gram of air had to be added during each run to keep the gas pressure constant.

Blechschmidt[8] has obtained a linear relationship between time of sputtering and amount of deposit. The linear relationship indicated in the curve between sputtering time and color cycle growth suggests the possibility of using the number of color rings as a basis for comparing the amount of material deposited under similar conditions.

Films Sputtered in Nitrogen

Early in the course of the work it was noticed that if the sputtering was carried on for several hours in dry air, without constant gas flow, the last films produced were more opaque and less brilliantly colored than the first. This, in addition to the fact that a considerable quantity of gas always disappeared during the sputtering process, suggested that some element of the air, responsible for the color phenomenon, was being exhausted. Pure gases were therefore tried.

Nitrogen was produced by heating a solution of sodium nitrite and ammonium chloride in distilled water. In an atmosphere of pure nitrogen a heavy brown opaque film was deposited. The opacity decreased with distance from the center of the deposit. Unless the apparatus was clean and the nitrogen pure, a certain amount of color persisted around the edges. Consequently the constant flow method was used to insure clean gas.

Films deposited in nitrogen could be removed by hard rubbing. A drop of hydrochloric acid immediately removed the part it touched and liberated a considerable quantity of gas. Exposing the film to the air caused it to gradually lose its opacity and take on the transparent nature and the color of films produced in air. Immersion in boiling water practically cleared the opaque deposit[9] and, in only a few minutes, produced the color rings. Heating the film in oxygen had the same effect. The complete change took place in oxygen at 200°C in about ten minutes with a thick brown film. The time required was much longer if the original plate showed other colors around the edge in addition to brown. Fig. 4 is a

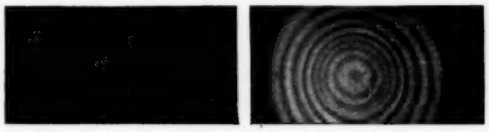

Fig. 4.

photograph of a deposit of this type before and after heating in oxygen. It is apparent that the material of the film produced in nitrogen is not in its most stable form.

Even though tin and nitrogen do not unite under ordinary conditions,[10] the excited state of the gas, and finely divided form of the metal in cathodic sputtering, increases the possibility for such combination to take place.[11] In order to test for a nitride of tin[12] the film was removed with dilute hydrochloric acid and the solution made slightly alkaline with sodium hydroxide. The gas liberated by heating this solution produced a brick red precipitate on passing through Nessler's solution ($K_2 Hg I_4$). Since the acid, base and

[8] E. Blechschmidt, Ann. d. Physik **81**, 999 (1926).

[9] Mellor, *A Comprehensive Treatise on Inorganic and Theoretical Chemistry*, vol. VIII, p. 97. "Usually the nitride is decomposed by steam giving off ammonia. . . ." "When the nitrides are oxidized, free nitrogen is evolved and an oxide of the metal is formed."

[10] Ephriam. *Inorganic Chemistry*, 1926, p. 529.

[11] Mellor, *A Comprehensive Treatise on Inorganic and Theoretical Chemistry*, vol. VIII, p. 122. "H. Fischer and coworkers prepared an impure tin nitride. . . ." The method used was to spark tin electrodes in liquid nitrogen.

[12] Schimpf. *Manual of Volumetric Analysis.*

free nitrogen had been previously tested with negative results, it is shown that the nitrogen present must have come from a compound of tin and nitrogen, probably a nitride of tin. The characteristics of stannous imide (Sn N H) as stated by Bergstrom,[13] are very similar to those exhibited by the material of these films, but the absense of hydrogen in the gas used scarcely permits the conclusion that these films are stannous imide.

A microscopic study of the film just after it was sputtered showed only a smooth heavy layer under a magnification of about 1500 ×. As the film changed form in oxygen, small spots became transparent and grew larger and merged into one another. The cleared spaces showed the characteristic color film.

Films Sputtered in Hydrogen

Greater pressures were required for obtaining deposits in hydrogen than in oxygen or nitrogen, and the films always had mirror surfaces of high reflecting power. Traces of impurities in the hydrogen did not change the deposit. When the deposit was made very heavy, by continued sputtering, the film took on a pearly luster characteristic of a fine granular surface.

The deposit in hydrogen did not adhere as firmly to the glass base as did the color deposits obtained in air and oxygen. It could be readily removed by using hydrochloric acid and less easily by rubbing. Films exposed to the air for a period of three years did not noticeably change their appearance, indicating a stable deposit. Passing a Bunsen flame over the film removed its opacity and produced a slightly milky-colored residue which showed, by reflected light, a color phenomenon which was somewhat less intense than that shown by deposits in air. Further heating distorted this color form. Treatment with hydrochloric acid had little effect on this final color film. From all appearances the film deposited in an atmosphere of hydrogen was metallic tin.

Films Sputtered in Oxygen

Films deposited in oxygen were practically identical in appearance to those deposited in a constant flow of air. These deposits were extremely stable. Plates exposed to the air showed no change in three years. They could be rubbed without danger of effacing the color. Acid treatment affected such a deposit very slowly, several hours being required for the removal of the film. A microscopic study, with a magnification of about 1500 ×, did not reveal any definite particle formation. It showed a smooth tinted surface just as it appeared to the unaided eye. It is known that tin poured at high temperatures sometimes shows iridescent colors[14] due to a surface oxide. The characteristics of the films sputtered in oxygen indicate the deposit to be stannic oxide.

Conclusions

The repetition of color cycles makes it difficult to believe that the color is caused by the film structure, such as size of particle or aggregate. Since there was no apparent variation in the brilliancy of the colors when the films were immersed in water or in carbon bisulphide, the possibility that the colors are due to a peculiar surface irregularity (resonance phenomenon) seems unlikely.

All observations lead to the conclusion that these colors in films of sputtered tin are due to an interference effect resulting from a varying thickness of the transparent deposit.

(1) Only those films which were almost transparent showed the brilliant colors.
(2) Colors as viewed by transmitted light and reflected light were complementary.
(3) The colors, in repeating cycles, varied in their brilliancy in exact agreement with Newton's color rings.
(4) Repeating color cycles on this theory require a deposit in the form of a flattened hemisphere. The varying opacity of the films produced in nitrogen indicate that the deposits were of this form.

It was found possible to produce a nitride (or imide) of tin by sputtering from a tin cathode in an atmosphere of nitrogen.

This work was carried on under the kind direction of Dr. Lester I. Bockstahler and with his active help. To him the author expresses his appreciation.

[13] F. W. Bergstrom, J. Phys. Chem. **32**, 439 (1928).

[14] Mellor, *A Comprehensive Treatise of Inorganic and Theoretical Chemistry*, vol. VIII, p. 296.

Proceedings of the Seventeenth Annual Meeting of the Optical Society of America

LAKE PLACID CLUB, NEW YORK

October 13–15, 1932

THE seventeenth annual meeting of the Optical Society of America was held at Lake Placid, New York, October 13–15, 1932.

The meeting was opened Thursday, October 13, at 9:30 A.M. by President E. C. Crittenden.

WELCOME BY LAKE PLACID CLUB

At the session Thursday afternoon Mr. H. W. Hicks, Vice-President of the Lake Placid Club, officially welcomed the Society to the Lake Placid Club and gave a short history of the founding of the club by Melville Dewey.

PUBLIC LECTURE ON THE EARLY HISTORY OF OPTICS

On Thursday evening, October 13, Dr. K. K. Darrow, Bell Telephone Laboratories, gave, by invitation, a lecture on the early history of optics. He traced the development from the fundamental concepts of optics from the earliest historical records down to the beginning of the 19th century.

SESSION DEVOTED TO A CENTURY OF OPTICS

The session Friday afternoon, October 14, was devoted to papers on *A Century of Optics*. The following papers were presented by invitation:

Sidelights on the Era of Young and Fresnel, by Professor E. L. Nichols, Cornell University.

The Electromagnetic Theory, by Dr. W. F. G. Swann, Bartol Research Foundation.

The Modern Theory of Light, by Professor E. U. Condon, Princeton University.

DEATHS DURING THE YEAR

Before taking up the program of invited papers Friday afternoon the Society paused to pay a tribute to members it had lost during the year. On request by the President the Secretary read the names of members who had died. Among them were six whose deaths represented an unusual loss to the Society.

At the request of the President, Mr. L. A. Jones spoke briefly of the work of George K. Burgess, Director of the Bureau of Standards, and of George Eastman, founder of the Eastman Kodak Company, and of the service they had rendered the Society through the organizations which they directed.

Professor J. P. C. Southall spoke of the work of Charles S. Hastings, an honorary member of the Society, and of Adolph Lomb, who had been Treasurer of the Society since its foundation.

Dr. H. E. Ives spoke of the work of I. G. Priest and of L. T. Troland, both past presidents of the Society.

BUSINESS SESSION

A brief business session of the Society was held Saturday morning, President Crittenden presiding. Informal reports of the Secretary, the Treasurer, and the Business Manager of the Journal were presented by the Secretary. (*Note:* The Society's fiscal year being identical with the civil calendar year, the officers' *formal* reports are made as of December 31, each year.) He noted that in spite of the present economic situation the membership of the Society had not decreased, the new members being sufficient to balance the losses by deaths and resignations.

The President discussed briefly the considerable changes which had taken place in the Society. Business management of the publication of the journals would be taken over by the American Institute of Physics, the editorial handling to be left in the hands of the Optical Society of America. He noted that the incorporation of the Society would be completed before the next meeting and that the new By-laws would be submitted to the Society in connection with the incorporation.

The President announced the usual joint meeting with the Physical Society in New York City in February, noting that the place of the 1933 annual meeting had not yet been decided.

Vote of Thanks to Lake Placid Club

Professor A. C. Hardy moved a vote of thanks to the Lake Placid Club which by its courtesy and hospitality had contributed to a highly successful and enjoyable meeting. The motion was carried unanimously and the Secretary was instructed to communicate it to the officers of the Club.

Invited Paper on Scattering of Light by Supersonic Waves

On Saturday morning after the business session Professor F. W. Sears of the Massachusetts Institute of Technology presented by invitation a paper by himself and Professor Debye on *Scattering of Light by Supersonic Waves*. This was accompanied by experimental demonstrations showing the beautiful spectra produced when light was passed through a liquid subjected to high frequency vibrations.

Group Conferences

The remainder of the day was devoted to group conferences. Two larger groups were organized, one on Colorimetry under the leadership of L. A. Jones and one on the Theory of Projection Systems under the leadership of W. B. Rayton. A number of smaller groups met informally.

Attendance

The attendance was as follows: Members 45, Guests, 25, Total 70.

Sessions for the Reading and Discussion of Contributed Papers

Sessions for the reading and discussion of contributed papers were held as follows:

October 13, 9:30 A.M.—Optical Instruments and Optical Design.
October 13, 2:00 P.M.—Visual Optics.
October 14, 9:30 A.M.—Physical Optics.

The authors' abstracts of these papers are appended.

Meetings of the Council

Sessions of the Executive Council were held as follows:

Thursday, October 13, at 10:00 P.M.
Friday, October 14, at 5:15 P.M.
Friday, October 14, at 9:00 P.M.

L. B. Tuckerman, *Secretary*

Minutes of the Executive Council

Annual Meeting at Lake Placid, New York

October 13 and 14, 1932

BESIDE the transaction of routine business, the following items of general interest to members of the Society were taken up:

1. Publications

The report of the Committee on Publications was accepted and approved, and a motion was made and carried that:

"The Special Committee on Publications be continued with power to negotiate and sign, on the basis of the report as approved, a contract with the American Institute of Physics for conducting the publication of the Journal of the Optical Society of America and the Review of Scientific Instruments during the calendar year 1933."

2. Incorporation

The Secretary presented the report of the tellers, Charles Bittinger, James E. Ives, and A. Q. Tool, appointed to canvass the vote on incorporation of the Society. The vote was:

For approval	267
For disapproval	3
Not voting	1

The Committee on Incorporation consisting

of: E. C. Crittenden, L. A. Jones, Adolph Lomb, W. B. Rayton, L. B. Tuckerman, and T. R. Wilkins, reported that in accordance with this action steps had been taken to complete incorporation of the Society.

3. Revision of By-laws

The Committee on Revision of the By-laws presented a revised copy of the By-laws. This was taken up item by item and fully discussed. A few minor changes in wording were suggested, and the report was approved as amended. The Committee was instructed to prepare the revised copy for submission to the members of the Society for adoption.

4. Appointments Made

Representative on American National Committee for International Congresses of Photography—A. C. Hardy.

Representative on the Intersociety Color Council in place of I. G. Priest—D. B. Judd.

Auditors of the accounts of Adolph Lomb as Treasurer of the Optical Society of America—J. P. C. Southall, C. L. Treleaven.

Directors of the American Institute of Physics, Incorporated—

L. A. Jones—term to expire December 31, 1933.
F. K. Richtmyer—term to expire December 31, 1934.
P. D. Foote—term to expire December 31, 1935.

5. Proxy of Optical Society of America at Annual Meeting of American Institute of Physics

The President and Secretary were authorized to designate a proxy to represent the Optical Society of America at the Annual Meeting of the American Institute of Physics in February, 1933.

6. Committee Authorized to Appoint Treasurer until General Election

It was moved and carried that: "In view of the urgency of the situation created by the unexpected death of Adolph Lomb, Treasurer of the Society, L. A. Jones, T. R. Wilkins, and W. B. Rayton shall constitute a committee of three with power to appoint on behalf of the Council, a treasurer to hold office until the next general election of the Society."

7. Ives Medal to be Awarded in 1933

The Council voted that the Ives Medal be awarded in 1933.

8. Transfers from Associate to Regular Membership

The name of each member elected during the year, and those previously elected and recommended for transfer, with recommendations from the Committee on Transfer were taken up in order and the following members were transferred to Regular membership: Walter Clark (913 R), John I. Crabtree (908 R), M. H. Eisenhart (910 R), Paul R. Gleason (903 R), Clarence H. Graham (932 R), William Herriott (926 R), John W. McFarlane (912 R), Julian Ellis Mack (924 R), Harry William Mountcastle (931 R), Wayne B. Nottingham (922 R), H. M. O'Bryan (927 R), Otto Oldenberg (904 R), Marion Edward Russell (918 R).

L. B. Tuckerman, *Secretary*

Seventeenth Annual Meeting—Program of Sessions for Contributed Papers*

(Titles and Abstracts of Papers)

Contributed Papers on Optical Instruments and Instrument Design

Thursday, October 13, 9:30 A.M.

A Large Double Crystalline Quartz Monochromator. W. E. Forsythe and B. T. Barnes, *Lamp Development Laboratory, General Electric Company.*

A large crystalline quartz double monochromator has been constructed for use in studying the ultraviolet, visible and infrared radiation from different sources. This instrument has Cornu prisms 10 centimeters high and 15 centimeters along the base. The lenses used are 12 centimeters in diameter and about 40 centimeters focal length for wave-length 3000A. All four lenses are focussed by the operation of a single calibrated wheel. The instrument can be set for any wave-length by turning a second calibrated wheel. A lever system makes the deviation angles for the two monochromator systems equal and keeps both prisms at minimum deviation. Two bilateral slits are used at the receiving end of the telescope. They are so mounted that they may be moved perpendicular to the axis of the telescope so that either can be brought to the axis. Attached behind the first slit is a thermopile and behind the other is a photoelectric tube so that either can be used as the measuring instrument without the necessity of removing the other one from its mounting. For purposes of calibration two slits were also used between the two monochromator systems. These slits are likewise so mounted that they can be accurately moved perpendicular to the axis of the instrument. Behind one slit a thermopile is mounted so that this thermopile can be used for measuring radiation which has passed through the first part of the instrument. Then, with the other slit in position, the same radiation can be measured with another thermopile after this radiation has passed through the second part of the instrument. These readings gave a measure of the transmission of the second part of the instrument. By reversing source and receiver the transmission of the first part of the instrument can be measured. The transmission of this instrument is about 15% for λ2500A and 20% for 3000A, and is between 25 and 30% for the visible and near infrared regions.

The present paper will appear in full in the Journal of the Optical Society of America.

The Development of a Microscope-Centrifuge after Harvey-Loomis. Gustave Fassin, *Institute of Optics, Rochester, N. Y.*

To measure the viscosity of the protoplasm by applying Stoke's law to the rate of movement of granules under the centrifugal force; to determine relative gravity and total volume of granules; and to observe the behavior of mitotic figures under centrifugal force, this new type of microscope has been developed.

The paper will deal with the different problems encountered in the development by the Bausch and Lomb Optical Company of an instrument of this type in the solution of which the author was able to assist. The instrument consists of a set of microscope objectives built into a streamlined rotor which carries the specimen and revolves at a speed of 10,000 r.p.m. developing forces of about 12,000 times gravity. A fixed eyepiece permits the observer to follow the centrifugal process under a magnification of from 100 to 200 times. An instrument will be demonstrated.

Bibliography:
Science **72**, 42 (1930).
Science **75**, 267 (1932).

A Modified Rochon Prism. O. W. Pineo, *Massachusetts Institute of Technology.*

The requirement of high light transmitting power for polarizing prisms used in photoelectric instruments is satisfied by a modified type of Rochon prism with much less expense than by the several more common types of polarizing prism.

The present paper will appear in full in The Review of Scientific Instruments.

A Method of Measuring Axial Chromatic Aberration in an Objective Lens. William Herriott, *Bell Telephone Laboratories.*

A method of measuring axial chromatic aberration is described in which an image of a line grating test object illuminated by a monochromator is formed by the lens under test. The image thus formed is projected onto a steeply inclined photographic plate by means of a highly corrected microscope objective. Individual exposures are made at selected wave-lengths and a curve showing the change of image position as a function of wave-length for the lens under test is readily derived from measurement of the developed plate. Data are given showing the order of agreement attained between computed values of axial chromatic aberration and values obtained by this method.

The present paper will appear in full in the Journal of the Optical Society of America.

Lantern Slides for Illustrating Lectures. W. E. Forsythe, *Lamp Development Laboratory, General Electric Company.*

Lantern slides can be a very great help both to the lecturer and to the audience but sometimes this is often greatly impaired by the character of the slides used. A slide that does not show plainly what it is made to illustrate is worse than useless.

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* The abstracts were preprinted in the program subject to correction by the authors. Corrections that have been communicated to the secretary have been made in the abstracts reprinted below.

Many times a slide made from a picture of a spectrum taken to show some interesting phenomena is so made that the audience cannot possibly see the illustration of the important phenomena. There are ways and means known to those skilled in the art of so making the slide that it will show just what it is intended to show.

For showing equations, tables of data or writing on a curve, a good rule to follow is to have each full length line on a slide made up of not more than fifty letters. Such printing can be done either by typewriter or by the use of templets, which can be used by almost anyone, rather than sloppy hand printing or writing as one often sees.

Hand made slides, that is slides where the printing is done directly on the slide, should in general, be avoided unless the maker is very skillful. Such blunders as having the slides so made that the printing or illustrations are turned through 90° are inexcusable.

This picture has another side. A lecturer often prepares good slides of the proper size and then finds that the person responsible for projection does not furnish a suitable projection system. Poor light, poor screen, poor heat screening, or poor projection may ruin even the best slides. If slides are prepared for the standard projection system where the final picture as observed by the audience is about ten by eight feet, and then projected onto a screen which is about four by three feet, the slides will of course not show up to the best advantage.

A number of slides illustrating the above comments will be shown. Most of these slides have been made from memory of slides that have been observed at some of our recent technical meetings.

Contributed Papers on Visual Optics

Thursday, October 13, 2:00 P.M.

Spectral Energy Distribution, Temperature and Color Temperature of the Magnesium Flame in Air. Brian O'Brien and T. A. Russell, *Institute of Optics, Rochester, N. Y.*

By using a method previously described,[1] the energy distribution in the spectrum of magnesium ribbon burning in air has been determined from λ2500 to 9700A. The distribution in the continuous spectrum over the above range is approximately that of a gray body at 3750°K.

The usual method of flame temperature determination by spectrum line reversal is not applicable to flames such as magnesium having appreciable opacity produced by scattering by solid or liquid particles within the flame. Use has been made, therefore, of a pseudo reversal method in which light from a continuous spectrum source, passing through low temperature sodium vapor, is combined with light from a flame containing sodium by means of a silvered grid in the plane of a lens which images, superimposed, the flame and continuous source upon the slit of a spectrometer. The observations can be treated as in the case of true flame reversal, both methods yielding the same result when tested on a Bunsen flame transparent except at the *D* lines. The magnesium flame temperature determined by this method is in fair agreement with that predicted from the continuous spectrum, and also with the temperature calculated on the assumption of negligible dissociation of MgO in the flame.

The color temperature of the flame was determined photometrically by direct comparison with a standard light source and Davis and Gibson filters, and found to be 4700°K, but the line and band spectra present prevented an exact color match. The large difference between true and color temperature is caused by emission bands in the blue green. The present direct determination of color temperature is not in agreement with the results indirectly obtained by Eder.[2] Dziobek,[3] or Arens and Eggert.[4]

Bibliography:
[1] O'Brien, J. O. S. A. **22**, 426 (1932).
[2] Eder, Zeits. f. Wiss. Phot. **24**, 423 (1927); **27**, 337 (1930).
[3] Dziobek, Zeits. f. Wiss. Phot. **25** (1927–28).
[4] Arens and Eggert, Zeits. f. Wiss. Phot. **26**, 95 (1928).

Color Temperature of Tungsten-Filament Lamps as a Function of Time in Service at Constant Voltage. Deane B. Judd, *National Bureau of Standards.*

The ideal lamp for a standard of color temperature would be one which delivers constant radiant energy indefinitely. Actual seasoned lamps, however, operated at constant voltage, have been found to yield radiant energy of gradually decreasing color temperature due to evaporation from the filament. Since frequently the current falls off either only slightly or not at all, this decrease in color temperature is in large part to be ascribed to the accumulation of the familiar dark yellow film of tungsten on the inside surface of the bulb. On this account, the size and shape of the bulb is of importance; each type must be separately investigated.

The table shows the number of lamps of each type for which results have so far been obtained:

Description of lamp	Number tested	Hours burned	Initial color temperature
500-watt, pear-shaped, gas-filled, seasoned,			
(a) Crown filament (C7)	5	128	2848°K
(b) Circular-coil filament (C7A)	5	128	2848°K
400-watt, projection, tubular bulb, gas-filled, monoplane filament,			
(a) Unseasoned	10	64	3100°K
(b) Seasoned	5	64	2848°K
(c) Seasoned	5	64	2360°K
60-watt, squirrel-cage filament, commercial type, vacuum, seasoned (S17)	5	128	2360°K
60-watt, circular-coil filament, vacuum, seasoned	5	128	2360°K

The effect of seasoning the 400-watt projection lamps for one hour at about rated voltage, as determined from 20 lamps taken from stock, was a rise in color temperature from 3100 to about 3150°K about half of which occurred in the first five minutes.

Significant erratic variations in color temperature such as reported by Howe[1] and, over much longer intervals of burning, by Dziobek[2] have not been found.

Bibliography:
[1] H. E. Howe, *The Color Temperature of the Gas Filled Tungsten Lamp as a Function of Time in Service*, J. O. S. A. and R. S. I. 13, 304–305 (1926).
[2] W. Dziobek, *Uber die Verwendbarkeit der Wolfram-Vakuumlampe zu sensitometrischen Messungen*, Zeits. f. Wiss. Phot. 31, 96–97 (1932).

Color Filters for Altering Color Temperature (Pyrometer and Daylite Glasses). H. P. GAGE, *Corning Glass Works.*

The analysis of Wien's equation shows that a color filter in which the density $\delta = \log_{10}$ transmission, follows the equation $\delta = (6223/\lambda)(1/\Theta_1 - 1/\Theta_2)$ will reduce both the brightness and the color temperature of a complete radiator at temperature Θ_1 to that of a complete radiator at a lower temperature Θ_2. Such a color filter is useful as an absorbing screen in an optical pyrometer.

If a color filter has a spectral transmission such that the logarithm of transmittance plotted against reciprocal wave-length cutting this axis at a point corresponding to approximately 0.40μ, such a filter will serve to increase the color temperature of a source although reducing its brightness. The spectral formula of such a filter is $\beta t = 0.4343\ C_2\ (1/\lambda_1 - 1/\lambda)(1/\Theta_2 - 1/\Theta_1)$, Θ_1 being the temperature of the light source and Θ_2 that of the transmitted light expressed in accordance with Wien's equation. With a given filter the reciprocal color temperature is raised by the same amount irrespective of which portion of the color temperature scale is used and the change in reciprocal color temperature is proportional to the thickness of the glass color filter used if of the same melt. If points 2 and 3 of the spectrophotometric curve of such a Daylite glass are given then

$$\alpha t = 1/\Theta_1 - 1/\Theta_2 = 0.0001607(\beta_2 t - \beta_3 t)/(1/\lambda_2 - 1/\lambda_3).$$

By using αt to represent the change in reciprocal temperature for a given glass of thickness t, the change per unit thickness is α.

Most incandescent light sources may be described as having a spectral energy distribution in accordance with Wien's equation within the limits of the visible spectrum. Various phases of daylight produce a visual sensation equivalent to the energy distribution as given by Planck's equation or by a suitable but different choice of Θ the same distribution may also be represented by Wien's equation within the narrow limits of the effective visible spectrum 0.40μ to 0.70μ.

Bibliography:
Foote, Mohler and Fairchild, Jour. Wash. Acad. Sci. **VII**, 545 (1917).
Davis and Gibson Bur. Stand. Misc. Pub. 114.

The present paper will appear in full in the Journal of the Optical Society of America.

A Proposed Scale for Use in Specifying the Chromaticity of Incandescent Illuminants and Various Phases of Daylight. I. G. PRIEST, *National Bureau of Standards.*

It is proposed that reciprocal temperature (instead of temperature itself) be adopted as a conventional parameter for specifying the chromaticity of incandescent illuminants and various phases of daylight. It is recommended that the microreciprocal-degree absolute centigrade be adopted as the most convenient unit for expressing reciprocal temperatures. The following reasons are advanced for proposing these conventions: (1) A given small interval in reciprocal temperature is (approximately) equally perceptible as a difference in chromaticity regardless of color temperature. (2) A difference of one microreciprocal-degree is fairly representative of the doubtfully perceptible difference in chromaticity under the most favorable conditions of observation.[1] (3) Many computations are greatly facilitated by dealing with reciprocal temperature instead of temperature. This applies to pyrometric as well as colorimetric computations and is apparent from Wien's and Planck's formulas. (Cf. Gage's paper, this program.) (4) The substitution of reciprocal temperature for temperature is simple and the relation is easily remembered, whereas the translation from temperature to spectral centroid (as previously proposed tentatively[2]) is a tedious matter more or less likely to introduce confusion and misunderstanding.

The validity of the first reason given above is witnessed by the following statements (see also reason 4): (1) It was pointed out[2] in 1923 that a given difference in spectral centroid was approximately equally perceptible for all temperatures over a wide range. (2) It has recently been shown by Judd[3] that this empirical relation is valid over a greater range of temperature than previously tested, and is a more accurate representation than there had been reason to believe. (3) In 1925 Gage[4] pointed out that there must be an approximately linear relation between spectral centroid and the reciprocal of temperature. (4) Independently, Davis[5] has pointed out that, insofar as a given difference in spectral centroid is equally perceptible at all temperatures, a small difference in temperature of constant perceptibility must vary directly as the square of the temperature. (5) The rate of change of temperature with respect to reciprocal temperature is minus the square of temperature, i.e., $d\Theta/d(1/\Theta) = -\Theta^2$.

Bibliography:
[1] Cf. Judd, Bur. Stand. Res. Pap. No. 252, November, 1930. One microreciprocal-degree is approximately equivalent to $\Delta\lambda_C = 0.07 m\mu$.
[2] Priest: J. O. S. A. and R. S. I. **7**, 1190 (1923).
[3] J. O. S. A. **22**, 9 (1932).
[4] Letter to Gibson, December 9, 1925.
[5] Bur. Stand. Res. Paper No. 365, October, 1931.

The Brightness of the Stimulus and the Duration of the Stimulation as Factors in the Production of the "Flight of Colors" in the After-Images. WILLIAM BERRY, *University of Rochester.*

In certain types of after-images, produced by stimulating the eye by "white" light, sequences of chromatic and achromatic phases are observed. The phases of color, chromatic and achromatic, follow each other more or less rapidly during the course of the after-image until it is no longer visible. These phenomena were described by Helmholtz under the title *Farbiges Abklingen der Nachbilder.*[1] They have also been described by Fechner,[2] Seguin[3] and others.[4] Reference is made to the phenomena in texts written in English under the title of *The Flight of Colors in the After-Image.* Considerable uncertainty is indicated

in the literature concerning the precise nature of the phenomena.[5]

Two investigations of the problem have recently been carried on by the writer and Mr. Imus. The first was on the effect of the brightness of the stimulus. A range of brightness values from 11,208 to 0.093 millilambert was used with the duration of the stimulation constant at 60 seconds. The second experiment (carried on by Mr. Henry Imus) was on the effect of the duration of the stimulation. Durations ranging from 60 seconds to 1/200 second were used. The brightness value of the stimulus was held constant at 7400 millilamberts.

The results of the two investigations have so much in common as to lead to the supposition that the phenomena of the flight of colors in the after-image depends on the product of time and intensity of stimulation, i.e., according to these investigations, the product of the duration of the stimulation of the eye and the brightness of the stimulus.

Bibliography:
[1] H. Helmholtz, Physiological Optics **2**, 245–258.
[2] G. Fechner, *Ueber die subjectiven Nach-und Nebenbilder*, Pogg. Ann. **50**, 445–470 (1840).
[3] Seguin, *Recherches sur les couleurs accidentelles*, Comptes Rendus **41**, 413–431 (1854).
[4] W. Berry, *The Flight of Colors, etc.*, Psychol. Bull. **19**, 307–337 (1922).
[5] L. R. Troland, Psycho-Physiology **2**, 181.

Visual Acuity as a Function of Stimulus Distance. M. LUCKIESH AND FRANK K. MOSS, *Lighting Research Laboratory, General Electric Company.*

Although the importance of visual acuity is greatly overrated in considerations of everyday seeing, it is a fundamental visual function which is of much scientific importance. The relation between minimum perceptible size and level of brightness is well established for fixed distances of the object from the eyes. A recent investigation indicates that visual acuity varies materially with distance of observation. Data and discussion pertaining to this apparent anomaly will be presented.

The present paper will appear in full in the Journal of the Optical Society of America.

CONTRIBUTED PAPERS ON PHYSICAL OPTICS

Friday, October 14, 9:30 A.M.

The Hydrogen Effect in Certain Oxides. E. L. NICHOLS AND C. L. STANFORD, *Cornell University.*

The glow of platinum in contact with hydrogen, first noted by Davy (1816), has since been observed in the case of various other substances.[1]

The present study, by a new and very sensitive method deals chiefly with the rise in temperature of candoluminescent oxides and of certain activators.

The characteristic effect occurs only in the simultaneous presence of both H and O at the surface of the oxide; the heating of which is traced definitely to the formation of water vapor by the combination, without ignition, of the free gases.

The maximum heating occurs at starting temperatures between 450° and 600°C but measurable heating was recorded at much lower temperatures.

It is produced chiefly, perhaps exclusively, by nascent material and its perpetuation depends on the continued renewal of such material by the action of the free gases upon the oxide.

Addition of an activator does not greatly enhance nor modify the effect.

Bibliography:
[1] Davy, *Works*, Vol. VI, p. 8, 1816.
Dobereiner, Gilberts Annalen (1819).
Dulong and Thenard, Annales de Chimie et de Physique **23**, 440 (1823).
Faraday, *Researches*, Vol. I, p. 176 (1832).
Luggin, Journal fur Gasbeleuchtung **44**, 411 (1901).
Bone, *Transactions of the Royal Institution*, 1914.

The present paper will appear in full in the Journal of the Optical Society of America.

Standing Light Waves; Repetition of an Experiment by Wiener, Using a Photoelectric Probe Surface. HERBERT E. IVES AND THORNTON C. FRY, *Bell Telephone Laboratories.*

A classical experiment in optics was performed by Wiener in 1890,[1] in which he demonstrated the existence of standing waves by placing a thin photographic sensitive film at a small angle with a mirror and getting traces of the loops of the waves. Later a similar experiment was performed by Drude and Nernst,[2] with the substitution of a fluorescent probe surface. We have performed what is essentially a repetition of those experiments using a *photoelectric* probe surface, by depositing a quartz wedge by evaporation in vacuo on polished platinum, allowing a thin film of caesium to spontaneously deposit on it, and then measuring the photoelectric current at points along the wedge.

According to preliminary computation of the values of the electric force at the quartz surface,[3] we should expect the photoelectric current to vary in a periodic manner along the wedge, we should expect the "angle curves" to exhibit a wide variety of shapes, with reversals of the relation between "normal" and "selective" as ordinarily found with thin films of alkali metals, and the wave-length distribution of sensitiveness should exhibit maxima and minima moving systematically through the spectrum as the wedge is traversed. All of those predictions are found to be fulfilled. Points of interest in this experiment are: (1) Its intrinsic value as a further confirmation of the classical optical theory tested by Wiener; (2) its support of the theory which we have used to explain the vectorial photoelectric effect,[4] according to which the photoelectric current is proportional to the electric force in the alkali metal film; (3) its bearing on the elucidation of the properties of the caesium-silver-oxide photoelectric cell, which consists of a sensitive layer on top of a transparent layer of silver oxide on silver.

Bibliography:
[1] Wied. Ann. **40**, 203 (1890).
[2] Wied. Ann. **45**, 460 (1892).
[3] Fry, *Plane Waves of Light III*, J. Opt. Soc. Am. **22**, 307 (1932).
[4] Ives, *Vectorial Photoelectric Effect in Thin Films of Alkali Metal*, Phys. Rev. **38**, 1209 (1931).

The First Spark Spectrum of Chlorine and Its Structure. C. C. KIESS AND T. L. DEBRUIN, *National Bureau of Standards and University of Amsterdam.*

New observations of the spectra emitted by ionized Cl atoms have been made at the Bureau of Standards. The sources used in the work were Geissler tubes and the electrodeless discharge. These new wave-lengths, extending from 8400A in the infrared to 2250A in the ultraviolet, together with unpublished wave-lengths in the vacuum region by Bowen, have been used to extend the analysis of the structure of Cl II. Paschen has already given the principal quintet terms, and Bowen and also Murakawa have published some of the triplets. In the present investigation we have been able to extend both the quintet and triplet systems of terms, to establish some of the singlet terms and to tie the three systems together by means of inter-system combinations. In all respects the terms that have been found are those required theoretically. The quintet and triplet S terms that have ^4S of Cl III as limit form Ritzian series and fix the position of the deepest term of Cl II at approximately $3p\,^3P_2 = 192{,}000$ cm^{-1}, which gives 23.7 volts as the ionization potential of the singly ionized chlorine atom.

Bibliography:
Paschen, Ann. d. Physik **71**, 537 (1923).
Bowen, Phys. Rev. **31**, 34 (1928).
Murakawa, Zeits. f. Physik **69**, 507 (1931).

The present paper will appear in full in Bur. Standards J. Research.

The Zeeman Effect on Hafnium Lines. WILLIAM F. MEGGERS AND BOURDON F. SCRIBNER, *National Bureau of Standards.*

Regularities in the spark spectrum of hafnium (Hf II) were discovered[1] soon after new descriptions of hafnium spectra were completed.[2] A little later the first regularities in the arc spectrum of hafnium (Hf I) were announced.[3] The relative values of low energy levels (16 in Hf II and 7 in Hf I) and higher ones were established but in the absence of Zeeman effects the quantum numbers could not be fixed, so only a tentative identification of the lowest levels was proposed. Now the behavior of 280 hafnium lines in magnetic fields of 33,000 gauss has been studied. These lines lie in the interval 2393–4817A; 70 belong to the first and 210 to the second spectrum. Analysis of these new data has made it possible to extend the spectral classifications, assign the correct inner quantum numbers to the energy levels, and identify most of the spectral terms. In particular, it is pleasant to report that the Zeeman effects have confirmed our first suggested identifications of the low energy states. The normal state of neutral Hf atoms is represented by a triplet-F term ($d^2s^2.a^3F_2$) while that of singly ionized Hf atoms is represented by a doublet-D term ($d^2s.a^2D_{1\,1/2}$). Although the observed magnetic splitting factors for Hf show, for some levels, considerable departures from the Landé theoretical g values, the g-sum rule of Pauli is obeyed wherever it is tested.

Bibliography:
[1] W. F. Meggers and B. F. Scribner, J. O. S. A. and R. S. I. **17**, 83 (1928).
[2] W. F. Meggers, Bur. Standards J. Research **1**, 151 (1928).
[3] W. F. Meggers and B. F. Scribner, Bur. Standards J. Research **4**, 169 (1930).

The present paper will appear in full in Bur. Standards J. Research.

A Motion Picture Study of the Behavior of the Carbon Arc. L. V. FOSTER AND J. V. BUTTERFIELD, *Bausch and Lomb Optical Company.*

This investigation was carried out to ascertain the best operating condition for d. c. carbon arcs such as are used in photomicrography and micro-projection. The study was carried out by applying the 16 mm motor-driven motion picture camera and taking intermittently through the life of pairs of carbons motion pictures of the projected crater image. The set-up used will be described and the motion picture films taken will be projected.

The Measurement of Erythemal Ultraviolet Radiation. A. H. TAYLOR, *Lighting Research Laboratory, General Electric Company.*

The introduction of new types of artificial sources of ultraviolet radiation for therapeutic applications and general illumination has necessitated a thorough study of methods of appraising the ultraviolet output of such sources. During the past three years Lighting Research Laboratory has studied various methods and devices, including fluorescent glasses and various types of photoelectric cells. These have been compared with erythemal tests on untanned human skin, to determine which device or method gives results most nearly in agreement with the erythemal exposures.

The device giving results most closely in agreement with erythemal tests was found to be a cadmium photoelectric cell with a Corex D bulb. Tests with MAZDA S-1, S-2 and G-1 lamps gave results in very close agreement with erythemal tests. Sunlight was appraised about 50 percent higher by this cell than by the erythemal test, when the cell was calibrated with a Type S-1 lamp.

A portable two-stage amplifier has been built for measurement of the ultraviolet component in dual-purpose lighting. With this apparatus it is possible to cover the ultraviolet intensity range from a quartz mercury arc down to a few footcandles from MAZDA CX lamps (high-efficiency tungsten lamps in ultraviolet transmitting bulbs). This is a range of approximately 5000 to 1. This amplifier will be described and demonstrated at the meeting.

Bibliography:
Trans. I. E. S. **26**, 711 (1931).
Bur. Standards J. Research **8**, 759 (1932).

The present paper will appear in full in the Journal of the Optical Society of America.

Optical Society of America, Inc.

Notice of Election of Officers

President, Vice-President } for a term of two years

Secretary, Treasurer } for a term of four years

Members at large of the Board of Directors
Two for a term of two years
Three for a term of four years

The following Committee on Nominations has been appointed and confirmed in accordance with Article III, Section 6 of the By-laws:

F. K. Richtmyer, Chairman,
Rockefeller Hall,
Cornell University,
Ithaca, New York.

I. C. Gardner,
Bureau of Standards,
Washington, D. C.

G. R. Harrison,
Department of Physics,
Massachusetts Institute of Technology,
Cambridge, Massachusetts.

Brian O'Brien,
1224 Genesee Street,
Rochester, New York.

Harold W. Webb,
Columbia University,
New York, New York.

It will be the duty of this committee to make nominations for the above-mentioned election. The Committee report is to be made not later than July 15, 1933.

Although, after the committee has made its report, an opportunity will be given for additional nominations by petition, members are urged, as soon as possible, to suggest names which should be considered by the committee. Suggestions may be sent to the Chairman or any other member of the Committee. Only regular and honorary members are eligible to election.

A membership list was published in the J.O.S.A. **21**, 449–484 (1931). Later transfers to regular membership were given in the Secretary's Annual Report published in the J.O.S.A. **22**, 237 (1932).

SIGNED

L. B. Tuckerman, *Secretary.*